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AUTHOR(S) Malina, F. J. DATE

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CALIFORNIA INSTITUTE OF TECHNOLOGY

AIR CORPS JET PROPULSION RESEARCH

GALCIT Project No. 1

Report No. 12

TAKE-OFF AND FLIGHT PERFORMANCE OF AN A-20A AIRPLANE AS AFFECTED BY AUXILIARY PROPULSION SUPPLIED BY LIQUID PROPELLANT JET UNITS

F. J. Malina

California Institute of Technology
June 30, 1942

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TAKE-OFF AND FLIGHT PERFORMANCE OF AN A-20A AIRPLANE AS AFFECTED BY AUXILIARY PROPULSION SUPPLIED BY LIQUID PROPELLANT JET UNITS

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California Institute of Technology

June 30, 1942

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M. G. Cassell.......................Installation Inspector
L. A. Brady.........................Crew Chief
A. C. Loedding......................Observer

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B. H. Forman........................Chief Mechanic, Jet Operator in Flight Tests
R. Terbeck..........................Assist. Chief Mechanic
W. H. Wheeler.......................Mechanic
A. Richardson.......................Mechanic
W. Gibson...........................Mechanic
L. Gaul.............................Mechanic's Helper
W. C. Stephenson....................Mechanic's Helper
H. Farrell..........................Mechanic's Helper
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ACKNOWLEDGEMENTS

The flight tests were greatly assisted by the personnel and facilities made available by the Commanding Officer of the Muroc Bombing and Gunnery Range Detachment.

The major portion of the jet equipment was installed at the Lockheed Airport, Burbank, California and the Pacific Airmotive Corp. kindly permitted the use of some of their equipment.

I. INTRODUCTION AND SUMMARY

During August, 1941, the Air Corps Jet Propulsion Research Project successfully completed a series of flight tests with the Ercoupe, a light airplane, equipped with six 25 lb. thrust solid propellant jet units. The results of the tests showed that auxiliary jet propulsion could, with great advantage, improve aircraft take-off performance, and also flight performance for short periods of time. (Cf. Ref. 1)

The solid propellant jet units used in these flight tests were later found to have unsatisfactory storage qualities, necessitating further research before larger units of this type could be recommended for service applications.

Paralleling the solid propellant research, work was being carried out by the Project on jet units of the liquid propellant type. The engineering development of the liquid jet unit culminated rapidly when a suitable oxidizer and fuel were discovered. The Materiel Center chose the A-20A airplane for the flight tests analyzed in this report. The development of the liquid propellant installation and its operation during the flight tests are described in Reference 2.

The results of the A-20A flight tests indicate that the take-off characteristics of an aircraft can be greatly improved even though the airplane has not been originally built to incorporate auxiliary jet propulsion equipment. In new types the provision for such equipment will permit greater freedom in the design of the aircraft for optimum performance, especially as regards range and useful load carrying capacity.

V. J. Martin in Reference 3 states that rapid advances in the design of high speed airplanes with high wing and power loadings have made the problem of take-off performance one of major importance.

Propellers chosen to give maximum efficiency at normal cruising or high speed are, as a result of such selection, usually very inefficient in the take-off region. Power loadings are kept as high as possible to increase range and payload, resulting in lower thrust-weight ratios. High speed performance necessitates high wing loadings to reduce parasite drag, with the result that take-off speeds are increased. These and other factors tend to increase the take-off distance to an extent such that they become critical in design, often determining the limiting values for power and wing loadings, and propeller diameters.

In the opinion of Dr. G. P. Thomson of England and also of the author, recent developments in the methods of assisting the take-off of conventional aircraft have made it possible to design future aircraft to fulfill efficiently their main purpose--to fly. Take-off prerequisites are no longer critical and need not hinder the airplane designer. Landing of the aircraft is thus the only remaining shackle that the ground imposes on the designer.

In the A-20A flight tests two jet units each supplying 1000 lb. thrust for 24 seconds were installed. If greater reductions in take-off distance or larger overloads are desired, jet units delivering higher thrust can be installed. Preliminary experiments have already been made by the Project with a single jet unit giving 2000 lb. thrust.

The flight tests analyzed in this report furnished information on the following problems:

1. Effect of auxiliary jet propulsion on the reduction of take-off run and distance to clear 50 ft. with and without overload.
2. Effect of auxiliary jet propulsion on high speed at 5,000 and 10,000 ft. altitude.
3. Effect of jet thrust on stability and control.
4. Effect of blast from the jet units on parts of the airplane.
5. Reliability of the jet installation.

In Table I the salient points of the flight tests are summarized.

TABLE I.

ITEM	A-20A Without Jet Thrust	A-20A with 2000 lb. Jet Thrust	Percent Reduction %
Take-off distance for 17,500 lb. gross weight, ft.	1540	1080	29.9
Take-off time for 17,500 lb. gross weight, sec.	18.5	13.5	27.0
Distance to clear 50 ft. for 17,500 lb. gross weight, ft.	2680	1810	32.5
Time to clear 50 ft. for 17,500 lb. gross weight, sec.	25.1	17.7	29.5
Take-off distance for 20,000 lb. gross weight, ft.	2320	1570	32.2
Take-off time for 20,000 lb. gross weight, sec.	25.1	16.8	33.1
Distance to clear 50 ft. for 20,000 lb. gross weight, ft.	3950	2680	32.2
Time to clear 50 ft. for 20,000 lb. gross weight, sec.	33.3	22.8	31.5
Maximum indicated airspeed at 5,000 ft., m.p.h.	252	300	19.0 (Increase)
Maximum indicated airspeed at 10,000 ft., m.p.h.	239	280	17.2 (Increase)

On the basis of the flight tests the following conclusions can be drawn:

1. The reduction in take-off distance and time due to auxiliary jet thrust agrees with theoretically predicted values very closely. The reduction in distance to clear a height of 50 ft. is not as large as expected and further flight tests with a service type jet installation are recommended.
2. The flight tests indicate that large increases in maximum speed can be obtained by means of auxiliary jet propulsion. Comprehensive flight tests with a jet installation delivering thrust for a period of approximately one minute are justified.
3. The use of twin jet units in the A-20A nacelle cones caused no difficulty with stability and control. Control of the airplane was satisfactory even when only one jet unit was delivering thrust. The pilot remarked that the airplane handled much easier than normally during the take-off phases when the jet units were operating.
4. The blast from the jet units caused no adverse effects after the fabric covering of the elevators was treated with fire-resistant paint and aluminized varnish. Recent experiments at the Project indicate that the jet flame can be effectively reduced by the addition of certain chemicals to the oxidizer so that treatment of the fabric on the A-20A elevators could be dispensed with.
5. During the flight tests 44 successive jet motor runs were made without any misfires or explosions. On the basis of the experience gained during the flight tests and following

recommendations of the Material Center a service type 1000 lb. thrust, 25 second jet unit can be designed. The service type unit is expected to have a value of at least 3.2 for the ratio of jet thrust to full weight of the jet unit and a value of 6 when the jet unit is empty. The ratio of impulse delivered to the full weight of the jet installation would have a value of 80 lb. sec. per lb., which is as high as has been so far obtained with the best unrestricted-burning type of solid propellant jet unit.

II. DESCRIPTION OF THE A-20A AIRPLANE

When the development of the 1000 lb. thrust liquid propellant jet unit had reached the stage for installation on an aircraft the Materiel Center made a study of existing service type airplanes to determine which would be most suitable. The A-20A airplane was chosen, as it promised to be the most easily adaptable to an experimental jet propulsion installation.

The A-20A airplane shown in Figs. 1 and 2 is a high performance bimotor, mid-wing monoplane with a tricycle landing gear and a single vertical surface. The entire airplane is duralumin clad with the exception of the control surfaces, which are covered with doped fabric.

The airplane normally carries a crew of three consisting of a pilot, bombadier, and gunner. A bomb bay divided into a fore and aft section occupies the central part of the fuselage.

The following information on the characteristics and performance of the airplane was furnished by the Materiel Center:

Airplane

Design gross weight..........................18,605 lb.
Weight empty.................................14,005 lb.
Wing span....................................61 ft. 4 in.
Length.......................................47 ft. 7 in.
Wing area....................................465 sq. ft.
Normal gasoline capacity.....................400 gallons
Maximum gasoline capacity....................500 gallons
Maximum oil capacity.........................46 gallons

Engines

Wright R-2600-3.

Take-off power rating--1600 h.p. at 2400 r.p.m.

Propellers

Hamilton Standard 3-blade constant speed.

Propeller diameter--11 ft. 3 in.

Distance to take-off over 50 ft. obstacle--2330 ft.

(Note: This figure is based on manufacturers guaranteed estimate.)

The A-20A had a number of design characteristics that made it vary favorable for flight tests to determine the effect of auxiliary jet propulsion on airplane performance. The tricycle type landing gear assured directional stability during the ground run. Each nacelle cone provided sufficient unused volume for the installation of a 1000 lb. thrust jet unit and furthermore permitted the jet thrust to act along the line of propeller thrust.

The thrust axis when projected rearward cleared the horizontal tail surface by a sufficient amount to allow the jet blast, if necessary, to extend beyond the tail. In Figs. 3 and 4 are drawn a side and top view of the A-20A together with outlines of the actual jet blasts.

In the fore section of the bomb bay two commercial nitrogen tanks for supplying propellant feed pressure were mounted. In the aft section of the bomb bay a separate hydraulic system was installed, since it was not considered advisable to use the system already on the airplane.

The rear cockpit, normally occupied by a gunner, was converted into a jet operator's compartment. From his seat the jet operator could observe the operation of the jet units in the nacelle cones and also the jet blasts.

In line with the above disposition of the jet propulsion equipment the Aircraft Laboratory of the Materiel Center designed and built suitable reinforcement for the engine nacelle structure. As a basis for the design of the reinforcement the following assumptions were made:

a. The thrust axis of the jet motor coincides with the thrust axis of the airplane.

b. The horizontal position of the center of gravity of the nacelle installation to be located one third the distance from the base of the engine nacelle tail cone to the tip of the same.

c. Weight of each nacelle installation, 500 lb.

In addition to the engine nacelle reinforcement the Aircraft Laboratory provided the main supporting structure for the nacelle jet installation, altered the nacelle cone covering, provided mounting brackets for the nitrogen tanks, ran lines between the nacelle cone firewall and the jet operator's compartment, and mounted a panel for the jet operator's instruments.

After the above revisions had been completed the airplane was flown by Major P. H. Dane from Wright Field to Lockheed Airport, Burbank, California. At Burbank the Project installed the jet propulsion equipment in 10 days, whereupon the airplane was flown to the U. S. Air Forces Bombing and Gunnery Range, Muroc, California.

III. DESCRIPTION OF THE JET INSTALLATION

The 1000 lb. thrust liquid propellant jet unit designed for installation on the A-20A airplane is the culmination of three years of development work carried out by the Liquid Propellant Section of the Air Corps Jet Propulsion Research Project at the California Institute of Technology.

The development period was spent in investigating a number of special problems that arose from the specifications set up by the Army Air Forces Materiel Center for a jet unit suitable for installation on aircraft to (1) improve take-off performance, (2) increase the maximum speed for a period of the order of one minute, and (3) increase the rate of climb for a similar period of time.

The specifications included the following points:

a. The replacement of liquid oxygen by an oxidizer that is more easily transported and handled.

b. The use of a fuel that is most advantageous for the jet unit as long as it is easily handled and available in large quantities.

c. The choice of a propellant supply system that would necessitate the least possible alteration to existing aircraft.

d. The design of the jet unit to emphasize lightness in weight and compactness.

e. The restriction of the size of the exhaust jet to a minimum possible.

f. The control of the jet unit to be automatic to the extent that operation of the unit is feasible by the pilot from the cockpit.

A suitable oxidizer for replacing liquid oxygen was found by J. W. Parsons in 1939 and preliminary experiments with the oxidizer are described in Reference 4. At first extensive research was carried out with gasoline as a fuel. (Reference 5) The ignition of this fuel with the oxidizer presented a serious problem. Then, when in an installation designed for light weight an unstable type of oscillation appeared during the combustion process, after ignition was accomplished, the gasoline was replaced, at the suggestion of the author, by a new fuel. This fuel ignites spontaneously with the oxidizer, in an appropriately designed jet motor, thus eliminating the necessity of an auxiliary ignition system. The rapid rate of burning of the new fuel with the oxidizer does not give rise to the unstable oscillation which occured with gasoline.

The design of the jet unit was developed under the direction of Dr. M. Summerfield who also supervised the design of the A-20A jet unit installation which was carried out by W. B. Powell and E. G. Crofut. A detailed description of the above work is reported in Reference 2.

Since this report is concerned primarily with the flight tests of the A-20A airplane the jet propulsion installation will be discussed here only briefly.

The jet propulsion equipment was constructed at the Air Corps Jet Propulsion Research Project. Two identical jet units characterized by the following performance specifications were built:

Rated thrust........................1000 lb.

Duration of rated thrust...........24 seconds.

Propellant consumption.............5.76 lb. per sec.

Propellant feed pressure...........[illegible] lb. per square inch.

Chamber pressure...................300 lb. per square inch.

In Fig. 8 a photograph of the jet motor is shown and in Fig. 9 a typical curve of thrust delivered as function of time.

Since the main purpose of the projected flight tests was to gain experience with the operation of a liquid propellant type of jet unit on an airplane, effort was directed toward achieving safety and reliability rather than lightness and ease of servicing. In fact, by the time the airplane was ready for the super-performance tests it had become a rudimentary flying jet laboratory.

The jet installation consisted of these component parts:

1. Two jet motors: one located in each nacelle cone.
2. Four propellant tanks; two located in each nacelle cone.
3. Two remotely operated propellant throttle valves; one located in each nacelle cone.
4. A pair of carbon tetrachloride fire extinguishing sprinklers in each nacelle cone.
5. Two commercial 200 cu. ft. nitrogen tanks in the forward bomb bay.
6. A nitrogen pressure regulator in the rear gunner's cockpit.
7. Hydraulic system for operating the propellant throttle valves.
8. Signal system between the pilot and jet operator.

A complete circuit diagram of the installation is drawn in Fig. 10. Two views of the uncovered jet unit mounted in the nacelle cone are shown in Figs. 11 and 12 and with the nacelle cone cover in place in Fig. 13. An excellent idea of the size of the nacelle jet installation can be obtained by referring to Fig. 14.

Views of the mounted nitrogen tanks, the hydraulic system, and the jet operators compartment are shown respectively in Figs. 15, 16, and 17.

The weights of the component parts of the jet installation are itemized in the following breakdown:

2 jet motors	180 lb.
4 propellant tanks	142
2 commercial nitrogen tanks	257
Valves, controls, and lines	69
Complete jet units, empty	648 lb.
Propellants	288
Nitrogen	36
Complete jet units, full	972 lb.
Instruments, auxiliary hydraulic system, fire extinguisher systems, armor plate, shock absorbers, nacelle reinforcement, and miscellaneous structure	450 lb.
Total weight of experimental installation	1422 lb.

As previously stated the above weights are much larger than necessary in a service type of installation. For example, since the completion of the flight tests the weight of the jet motor has been reduced from 90 lb. to approximately 25 lb. or 50 lb. for two jet motors compared to the 180 lb. weight of the experimental motors.

A service type of jet installation for the A-20A airplane, delivering 2000 lb. thrust for 25 seconds, is in the design stage at present, and has all the equipment in the space available in the nacelle cones with the exception of the pilot control. The estimated weight of this design is 300 lb. empty, 625 lb. with propellant and nitrogen tanks full. This corresponds to a thrust to weight ratio ($2000 \div 625$) of 3.2 and an impulse to weight ratio ($2000 \times 25 \div 625$) of 80 lb. sec. per lb.

The experimental jet installation used in the A-20A flight tests was completely satisfactory from the point of view of reliability. A total of 44 successive jet motor runs were made without any misfires or explosions. During the preliminary experiments on the airplane faulty check valves interfered with the propellant flow in the right jet unit and the lack of a vent hole in the hydraulic reservoir caused lack of synchronization in the starts of the two jet units. After these mechanical difficulties were discovered the operation of the jet equipment was as planned.

IV. FLIGHT TEST PROCEDURE AND DESCRIPTION OF TESTS

The flight tests of the A-20A airplane were carried out at Muroc Dry Lake, U. S. Air Forces Bombing and Gunnery Range, Muroc, California, during the period April 7 to April 24, 1942. A special take-off course was laid out on the lake bed at the north end of the lake. A stripe approximately 3 feet wide and 12,000 ft. long was marked with road oil to assist the pilot in keeping a straight path during the take-off run.

Take-off performance with and without auxiliary jet propulsion was recorded in cameras set up by the Flight Engineering and Factory Inspection Division of the Civil Aeronautics Administration. A description of the personnel, equipment used, and the results of the analysis of the film exposed are given in Army Air Forces Report No. 3 entitled "Space Time Records of Take-off Performance of A-20A Airplane With and Without Assistance from Jet Propulsion." A copy of this report is reproduced in Appendix A of this report.

In order to obtain an immediate estimate of the take-off performance the take-off distance was observed visually and the take-off time was clocked with a stop-watch. The results of these observations are tabulated in Table II.

These Tables also include a complete list of tests that were carried out on the airplane with jet units installed. A discussion of each test, from the point of view of the effect of the jet unit installation on the airplane, will be discussed later in this section. The development of the jet units at the Air Corps Jet Propulsion

TABLE II (PART 1)

FIELD DATA ON THE A-20A FLIGHT TESTS

TEST NO.	DATE	TIME OF DAY	PURPOSE OF TEST	GROSS WEIGHT LB.	JET THRUST LB.	PRESSURE ALTITUDE FT.	ENGINE MANIFOLD PRESSURE In. Hg.	PROPELLER R.P.M.	INDICATED TAKE-OFF SPEED M.P.H.	TAKE-OFF DIST. FT.	TAKE-OFF TIME SEC.
1	9/4/42	3:30 pm	5 sec. jet test, airplane stationary, props. on.								
2	10/4/42	4:00 pm	Same as Test No. 1, props. off.								
3	11/4/42		Same as Test No. 2								
4	11/4/42		Static thrust of props								
5	13/4/42	1:40 pm	Same as Test No. 1.								
6	13/4/42	3:10 pm	Simulated yaw test, on ground.								
7	14/4/42	4:30 pm	Taxi run with jets.								
8	14/4/42	5:00 pm	Take-off, jets on part of ground run.								
9	15/4/42	4:40 pm	Yaw test in flight.								
10	15/4/42	6:45 pm	Take-off, with jets.	19,504	2,000	2,500				1,320	13.6
11	18/4/42	9:50 am	Take-off, without jets	17,908		2,060			100	1,490	17.6
12	18/4/42	10:10 am	Take-off, with jets.	17,860	2,000	2,060			95	1,200	13.6
13	18/4/42	10:35 am	Take-off without jets.	17,464		2,060			100	1,490	17.0

TABLE II (PART 2)

FIELD DATA ON THE A-20A FLIGHT TESTS

TEST NO.	DATE	TIME OF DAY	PURPOSE OF TEST	GROSS WEIGHT LB.	JET THRUST LB.	PRESSURE ALTITUDE FT.	ENGINE MANIFOLD PRESSURE In. Hg.	PROPELLER R.P.M.	INDICATED TAKE-OFF SPEED M.P.H.	TAKE-OFF DIST. FT.	TAKE-OFF TIME SEC.
14	13/4/42	3:05 pm	Take-off, without jets	17,674		2,060			100	1,47[illegible]	17.6
15	13/4/42	6:10 pm	Take-off, without jets	17,908		2,060				1,500	17.6
16	18/4/42	6:18 pm	High speed with jets at 5000 ft.	17,908	2,000	5,000	39, rose to 40	2,200			
17	19/4/42	3:07 pm	Take-off, with jets	17,908	2,000	2,200	Throttle	slipped		1,195	
18	21/4/42	7:10 am	Take-off, with jets	17,908	2,000	2,340	41	2,450	100	1,190	13.8
19	21/4/42	9:00 am	Take-off, with jets	17,830	2,000	2,340	41	2,450	100	1,100	13.4
20	21/4/42	9:20 am	Take-off, without jets	17,464		2,340	41	2,450	100	1,730	18.5
21	21/4/42	1:15 pm	Take-off, without jets	18,916		2,390	41	2,450	103	1,600	18.5
22	21/4/42	1:55 pm	Take-off, with jets	18,838	2,000	2,390	41	2,450	103	1,095	13.2
23	21/4/42	2:05 pm	Take-off, without jets	18,472		2,390	41	2,450	100	1,530	18.0
24	21/4/42	4:15 pm	Take-off, with jets	18,682	2,000	2,390	41	2,450	103	1,310	15.6
25	22/4/42	8:55 am	Take-off, without jets	18,916		2,370	41	2,450	103	1,930	20.6
26	22/4/42	9:10 am	Take-off, without jets	18,838		2,370	41	2,450	104	1,733	19.2
27	22/4/42	9:45 am	Take-off, with jets	18,760	2,000	2,370	41	2,450	105	1,160	13.6

TABLE II (PART 3)

FIELD DATA ON THE A-20A FLIGHT TESTS

TEST NO.	DATE	TIME OF DAY	PURPOSE OF TEST	GROSS WEIGHT LB.	JET THRUST LB.	PRESSURE ALTITUDE FT.	ENGINE MANIFOLD PRESSURE In. Hg.	PROPELLER R.P.M.	INDICATED TAKE-OFF SPEED M.P.H.	TAKE-OFF DIST. FT.	TAKE-OFF TIME SEC.
28	22/4/42	9:40 am	Take-off, without jets	18,394		2,370	41	2,450	105	1,365	20.0
29	22/4/42	12:00 am	Take-off, without jets	18,604		2,370	41	2,450	105	1,705	
30	23/4/42	1:20 pm	Take-off, without jets	19,891		2,340	41	2,450	107.5	2,245	22.4
31	23/4/42	1:55 pm	Take-off, with jets	19,813	2,000	2,340	41	2,450	107.5	1,480	15.8
32	23/4/42	2:05 pm	Take-off, without jets	19,447		2,340	41	2,450	107.5	2,270	23.0
33	23/4/42	4:00 pm	Take-off, with jets	19,657	2,000	2,360	41	2,450	107.5	1,430	15.5
34	23/4/42	4:05 pm	Take-off, without jets	19,291		2,360	41	2,450	107.5	2,070	21.0
35	23/4/42	5:50 pm	Take-off, with jets	19,969	2,000	2,360	41	2,450	107.5	1,430	15.5
36	23/4/42	6:05 pm	Take-off, without jets	19,603		2,360	41	2,450	107.5	2,240	22.0
37	24/4/42	9:15 am	Take-off, with jets	17,830	2,000	2,200	41	2,450	100	1,010	11.8
38	24/4/42	11:10 am	High speed with jets at 10,000 ft.	17,917	2,000	10,000	34	2,300	100		

Research Project and a critique of the operation of the jet units during the flight tests can be found in Air Corps Jet Propulsion Research Project, Report No. 13 (Reference 2). A comprehensive record of these flight tests was obtained by means of motion pictures in color, and a film is available for projection from a 16 mm. projector.

In addition to the take-off distance and take-off time the following data are given in TableII: Gross weight, jet thrust, duration of jet thrust, engine manifold pressure, propeller r.p.m., and take-off velocity.

The flight test program called for a bracketing procedure consisting of an unassisted take-off before and after each assisted take-off. This procedure was followed in most cases. A greater number of take-offs was not carried out due to the limited time available for the flight tests.

The gross weight of the airplane was determined for each take-off according to the method described in Appendix B. Although direct weighing for each test was not possible it is estimated that the gross weight is accurate to within ± 0.5%.

It will be assumed, on the basis of test stand experiments at the Project, that each jet unit delivered 1000 lb. thrust for a period of 24 seconds.

The engine manifold pressure, propeller r.p.m., and take-off velocity were observed visually by the pilot and are therefore approximate data only.

The static thrust delivered by the propellers was measured (Figs. 18 and 19) by means of a tension gage borrowed from the Structural Research Department of the Lockheed Aircraft Co. It was found that at an engine manifold pressure of 42"Hg and 2500 r.p.m. the propellers delivered an average static thrust of 5925 lb.

A discussion, in chronological order, of the tests carried out follows:

<u>April 9, 1942</u>

Test No. 1: For the first operation of the jet units the propellant tanks were filled for a 5 second test. The nacelle cones covering the jet installations were left off. The airplane was held stationary and the engines were run at half throttle. (Fig. 20) The left jet unit operated satisfactorily. The right jet unit ran for 25 seconds at reduced thrust and was finally stopped by the jet operator. The start of the right unit lagged the left unit by approximately 4 seconds. The right jet unit was inspected and it was suspected that metal chips found in the propellant injector restricted the flow.

<u>April 10</u>

Test No. 2: Test No. 1 was repeated without the engines running. Again the right jet unit functioned improperly. There was an indication from the smoky jet blast that the mixture ratio of the right unit fluctuated during the run. The right unit was carefully inspected, but no mechanical fault could be found that caused the faulty operation.

<u>April 11</u>

Test No. 3: Test No. 2 was repeated and again the right jet unit failed to deliver its rated thrust. Both units started together and the left unit ran satisfactorily.

To discover the cause of the low propellant flow in the right unit the propellant tanks in both units were filled with water and a run simulated. (Cf. Fig. 21) The flow of water from the right unit was found to be at a rate much lower than from the left unit. This indicated that the check valves in the right unit were restricting the flow. Upon removing the check valves it was found that the ballsprings were not of the specified strength and under the feed pressure had compressed to such an extent that the flow of each propellant was throttled. It was decided to completely remove the check valves in the propellant lines in both jet units.

Test No. 4: The static thrust delivered by the airplane propellers was measured. Ropes were attached to the landing gear and to a gage which was anchored to an International Harvester Roustabout. At a manifold pressure of 42"Hg and 2500 r.p.m. an average static thrust of 5925 lb. was recorded.

April 13

Test No. 5: Test No. 3 was repeated, and with the faulty check valves removed both jet units operated satisfactorily. The propellant mixture ratio was slightly rich in both jet units.

Test No. 6: In preparation for a flight to determine the yawing effect of 1000 lb. thrust delivered by one of the jet units a simulated ground test was made with the airplane held stationary and the engines at full throttle. The right unit was run for approximately 10 seconds and stopped. Then both units were started and the right unit ran approximately 15 seconds while the left ran the full duration of 24 seconds. In this way an eccentric thrust loading was obtained first on the right side and then on the left side. The pilot was able to hold the plane in position with the brakes. He found that a low frequency vibration was noticeable when the jet units were operating.

April 14

Test No. 7: The airplane, with the nacelle cone coverings installed, was flown from the Muroc landing field to the lake bed course. The jet units were checked and a taxi run was made with the jet units operating. (Cf. Fig. 22) The airplane reached a ground speed of 135 m.p.h. in 20 seconds, the jet thrust was stopped, and the airplane brought to a halt. When the airplane reached take-off speed the pilot lifted the wheels off the ground and settled down again and continued the taxi run. The jet units operated satisfactorily and the pilot had no adverse comments.

Test No. 8: The jet units had the remainder of the propellants amounting to approximately 5 seconds of operation, left over from Test No. 7. It was decided in the take-off of the airplane for the flight to the hanger to operate the jet units until the propellants were exhausted. Both jet units operated satisfactorily. On checking the airplane in the hangar it was found that the cloth covered elevators were wrinkled. The elevators were sprayed with a new coat of dope which stretched out the wrinkles. The caues of the wrinkling was traced to heat radiated from the luminescent jet blast.

April 15

Test No. 9: A flight was made in the air to determine the yawing effect of jet thrust delivered by one jet unit to simulate the condition that might arise if one unit failed during the climb after take-off. (Cf. Fig. 23) The right jet unit was started alone when the airplane was in a climbing attitude at an indicated air speed of 150 m.p.h. After the right unit ran approximately 8 seconds the left unit was turned on. Since each unit had a propellant load for 24 seconds of jet thrust the left unit ran alone 8 seconds after the right unit stopped. The pilot found that the yawing moment p produced by a single jet unit could be easily counterbalanced by the rudder. The right jet unit was started at an altitude of 7500 ft. . The airplane reached an altitude of 9000 ft. during the period the jet thrust acted, at a rate of climb of 1900 ft. per second, approximately double of that obtained without auxiliary jet thrust. In the climb the indicated air speed was held to 150 m.p.h., corresponding to an engine manifold pressure of 27"Hg and 1900 r.p.m.

The pilot found that the weight of the jet unit installation caused the airplane to have a stability between neutral and slightly unstable. Very little jet thrust vibration was noticed by the pilot and the jet operator.

On checking the elevators no wrinkling was observed.

Test No. 10: The first take-off with auxiliary jet propulsion is shown in Fig. 24. Both jet units started together and functioned properly. Pilot remarked that airplane handled easier during take-off with jet thrust than without. First camera record of flight tests was taken by the C.A.A.

On checking the elevator surfaces it was found that the fabric had wrinkled again. A coat of dope was sprayed on and the wrinkles stretched out. The airplane was flown to the hangar and the tail surfaces were painted with two coats of fire-resistant paint and then a coat of aluminized varnish. In Fig. 25 the wrinkled elevator surface is shown and in Fig. 26 the elevator after treatment. No further wrinkling was encountered during the flight tests after the treatment was applied.

April 18

Test No. 11: Test to determine take-off performance in the 18,000 lb. gross weight condition without auxiliary jet propulsion. (Cf. Fig. 27) This gross weight was obtained by draining the main gasoline tanks.

Test No. 12: Same as Test No. 11 with auxiliary jet propulsion. (Cf. Figs. 28, 29, 30, and 31) The left jet unit lagged the right unit approximately 4 seconds in starting. Airplane yawed slightly when brakes released.

Test No. 13: Same as Test No. 11.

Test No. 14: Same as Test No. 11.

Test No. 15: Same as Test No. 11.

Test No. 16: The airplane was flown to 5000 ft. to determine the effect of auxiliary jet thrust on the maximum speed of the airplane. At an engine manifold pressure of 39"Hg and 2200 r.p.m. the airplane had an indicated air speed of 252 m.p.h. The air temperature was 23°C. The jet units were then turned on. When the jet thrust ceased the air speed indicator read 300 m.p.h. and the engine manifold pressure had risen to 40"Hg. The speed returned to 252 m.p.h. in from 6 to 8 seconds.

The left jet unit lagged the right unit approximately 4 seconds in starting. The elevator surfaces showed no wrinkles.

April 19

Test No. 17: Same as Test No. 13. The left jet unit again lagged approximately 4 seconds in starting. The brakes were released before the left jet unit started operating causing the airplane to yaw slightly to the left. After Test No. 16 the left airplane engine developed trouble. It was found necessary to put in new spark plugs and repair magneto points. During the repair of the engine the throttle was loosened and during Test No. 17 slipped from full throttle position so that this test is not considered reliable for take-off performance comparisons.

The lack of synchronization between the starting of the two jet units was becoming seriously objectionable. In checking the hydraulic system used to open the propellant throttle valves it was found that no vent had been provided in the oil reservoir. When the accumulator was pumped the reduction in pressure in the reservoir caused air to be sucked into the hydraulic system through the hand pump.

After a vent was provided and the hydraulic system bled the starting of the two jet units was synchronized to within less than 1 second. No further difficulty with synchronization was experienced during the remainder of the flight tests.

April 21

Test No. 18: Same as Test No. 12. Both jet units ran satisfactorily.

Test No. 19: Same as Test No. 18. Both jet units ran satisfactorily.

Test No. 20: Same as Test No. 11.

Test No. 21: Test to determine take-off performance for the 19,000 lb. gross weight condition without auxiliary jet propulsion. This gross weight was obtained by filling 16? gallons of gasoline in the main gas tanks.

Test No. 22: Same as Test No. 21 with auxiliary jet propulsion. Both jet units ran satisfactorily.

Test No. 23: Same as Test No. 21.

Test No. 24: Same as Test No. 22.

April 22

Test No. 25: Same as Test No. 21.

Test No. 26: Same as Test No. 21.

Test No. 27: Same as Test No. 22. Both jet units operated satisfactorily.

Test No. 28: Same as Test No. 21.

Test No. 29: Same as Test No. 21.

April 23

Test No. 30: Test to determine take-off performance for the 20,000 lb. gross weight condition without auxiliary jet thrust. This gross weight was obtained by filling the main gasoline tanks full, by hanging bags of lead shot in the forward bomb bay and by carrying Wm. Terbeck as a passenger in the forward bombadier's seat.

Test No. 31: Same as Test No. 30 with auxiliary jet propulsion. Both jet units operated satisfactorily.

Test No. 32: Same as Test No. 30.

Test No. 33: Same as Test No. 31. Both jet units operated satisfactorily.

Test No. 34: Same as Test No. 30.

Test No. 35: Same as Test No. 31. Both jet units operated satisfactorily.

Test No. 36: Same as Test No. 30.

April 24

Test No. 37: Same as Test No. 11 for the 18,000 lb. gross weight condition with auxiliary jet propulsion. Both jet units operated satisfactorily.

Test No. 38: The airplane was flown to 10,000 ft. to determine the effect of auxiliary jet thrust on the maximum speed of the airplane. (Cf. Fig. 32) At an engine manifold pressure of 34"Hg and 2300 r.p.m. the airplane had an indicated air speed of 239 m.p.h. The air temperature was 8°C. The jet units were then turned on. When the jet thrust ceased the air speed indicator read 280 m.p.h. W. B. Powell operated the jet units and E. G. Crofut observed the air speed indicator in the bombadier's compartment.

V. DISCUSSION OF THE RESULTS OF THE TESTS

The data on the flight tests as obtained from the C.A.A. film analysis and by observation at the field are summarised in tabular form on Page 4 of Appendix A. This table includes, for each run, the observed ground speeds, distances, times of run, wind speed and direction, outside air temperature, pressure altitude, and airplane weight.

Since a comparison of take-off performance of the A-20A with and without auxiliary jet propulsion is of primary interest the flight test data will be analyzed as observed, corrections being made only to reduce the data to zero wind velocity. The wind corrections for the take-off distance and take-off time were obtained from Figs. 33 and 34 respectively. The figures are reproduced from Reference 3.

The air borne distances required to clear a 50 ft. obstacle have been corrected by adding the product of head-wind speed and the air borne time and by subtracting the product of the tail-wind speed and the air borne time. The variation of the wind velocity in the 50 ft. layer has been neglected. The air speed at take-off is the algebraic sum of the ground speed and the corresponding wind speed.

The wind speed and wind direction fluctuated considerably during each take-off and thereby contributed to the experimental scatter that appears in the plotted results.

The changes in gross weight of the airplane due to the consumption of gasoline and the jet propellants during each take-off have been neglected. The jet propellants caused a maximum of 1.6% reduction in gross weight at the time they were exhausted.

The flight test data containing the corrections discussed above are summarized in Table III.

The variation of take-off air speed with gross weight is plotted in Fig. 35 for the airplane with and without auxiliary jet propulsion. The experimental scatter is seen to be quite large. Furthermore, all the experimental results consistantly show a greater scatter for the case of no jet thrust. Perhaps this can be accounted for by the improvement in take-off characteristics of the airplane brought about by the availability of 2000 lb. additional thrust from the jet units.

The distance traversed in the ground run, the horizontal component of the air borne path to clear 50 feet, and the total distance from the point the brakes were released to the point 50 feet was cleared are plotted against the airplane gross weight in Figs. 36, 37, and 38 respectively. Distances required with and without auxiliary jet thrust are included in these figures.

The take-off time, air borne time required to clear 50 feet, and the total time required to clear 50 feet from the point the brakes were released are plotted against the airplane gross weight in Figs. 39, 40, and 41 respectively. Times required with and without auxiliary jet propulsion are included in these figures.

On the basis of the faired curves in the above figures comparative results showing the effect of auxiliary jet thrust are given in Tables IV, V, and VI.

The percent reduction, due to the auxiliary jet thrust, in

TABLE III
SUMMARY OF CORRECTED FLIGHT TEST DATA

TEST NO.	ASSIST. OR UNASSIST.	GROSS WEIGHT, LB.	HEAD OR TAIL WIND, M.P.H.	GROUND SPEED AT TAKE-OFF, M.P.H.	AIR SPEED AT TAKE-OFF, M.P.H.	TAKE-OFF DISTANCE, UNCORR., FT.	TAKE-OFF DISTANCE, CORR., FT.	TAKE-OFF TIME, UNCORR., SEC.	TAKE-OFF TIME, CORR., SEC.	AIR BORNE DIST. TO CLEAR 50 FT., UNCORR., FT.	AIR BORNE DIST. TO CLEAR 50 FT., CORR., SEC.	AIR BORNE TIME TO CLEAR 50 FT., SEC.	TOTAL DIST. TO CLEAR 50 FT., UNCORR., FT.	TOTAL DIST. TO CLEAR 50 FT., CORR., FT.	TOTAL TIME TO CLEAR 50 FT., SEC.
10	A	19,504	6.1 H	116	122.1	1332	1465	15.0	15.6	1453	1390	7.2	2785	2855	22.2
11	U	17,908	1.0 T	108	107.0	1492	1460	18.3	18.1	1038	1050	6.0	2530	2530	24.3
12	A	17,860	3.0 T	115	112.0	1212	1150	15.1	14.7	1332	1360	6.3	2544	2510	21.9
13	U	17,464	0	111	111.0	1499	1500	17.6	17.6	1238	1240	6.8	2737	2740	24.4
17	A	THROTTLE SLIPPED													
18	A	17,908	2.9 T	115	112.1	1236	1185	15.1	14.8	831	850	4.4	2067	2035	19.5
19	A	17,830	1.7 T	112	110.3	1153	1120	13.9	13.8	813	830	4.5	1966	1950	18.4
20	U	17,464	6.1 T	116	109.9	1760	1590	19.9	19.1	1170	1220	6.4	2930	2810	26.3
21	U	18,916	8.1 H	103	111.1	1618	1860	19.9	20.3	1099	1020	6.7	2717	2880	26.6
22	A	18,838	6.6 H	106	112.6	1150	1280	14.3	15.1	1013	950	5.7	2163	2230	20.1
23	U	18,472	2.7 H	103	105.7	1553	1640	18.9	19.3	1834	1790	10.7	3387	3430	29.7
24	A	18,682	9.0 T	118	109.0	1376	1170	15.6	14.5	854	920	4.6	2230	2090	20.2
25	U	18,916	0	115	115.0	1977	1980	21.7	21.7	1314	1310	7.0	3291	3290	28.7
26	U	18,838	1.3 H	110	111.3	1780	1820	20.3	20.5	1148	1130	6.6	2928	2950	26.9
27	A	18,760	4.8 H	110	114.8	1218	1320	14.7	15.2	933	900	5.1	2151	2220	19.7
28	U	18,394	7.5 H	115	117.5	1918	2000	21.1	21.5	1462	1430	7.8	3380	3430	28.9
29	U	18,604	7.5 H	108	115.5	1761	1980	21.6	22.7	1472	1380	8.3	3233	3360	29.9
30	U	19,891	3.7 T	122	118.3	2298	2180	23.8	23.1	1673	1720	8.4	3971	3900	32.2
31	A	19,813	2.0 H	121	123.0	1537	1590	16.7	16.9	973	980	5.0	2510	2570	21.7
32	U	19,447	5.4 T	123	118.6	2325	2140	23.9	23.0	1590	1660	8.4	3915	3800	32.4
33	A	19,657	2.2 T	119	116.8	1485	1440	15.7	15.5	1015	1030	5.2	2500	2470	20.9
34	U	19,291	3.5 H	116	119.5	2093	2200	23.0	23.7	1262	1220	6.8	3355	3420	29.8
35	A	19,969	0.9 H	119	119.9	1488	1500	17.1	17.1	1197	1190	6.1	2685	2690	23.2
36	U	19,603	0.7 T	122	121.3	2283	2250	24.3	24.3	1403	1410	7.0	3691	3660	31.2
37	A	17,830	2.8 H	107	109.8	1048	1100	13.1	13.4	729	710	4.2	1777	1810	17.3

TABLE IV

		WITHOUT JET		WITH JET		REDUCTION DUE TO JET	
GROSS WT. LB.	TAKE-OFF AIR SPEED M.P.H.	TAKE-OFF DIST. FT.	TAKE-OFF TIME SEC.	TAKE-OFF DIST. FT.	TAKE-OFF TIME SEC.	TAKE-OFF DIST. %	TAKE-OFF TIME %
17,500	108.1	1540	18.5	1080	13.5	29.9	27.0
18,000	110.3	1670	19.3	1150	13.9	31.1	28.0
19,000	114.8	1960	21.6	1330	15.0	32.1	30.5
20,000	120.0	2320	25.1	1570	16.8	32.3	33.1

TABLE V

	WITHOUT JET		WITH JET		REDUCTION DUE TO JET	
GROSS WT. LB.	AIR BORNE DIST. TO CLEAR 50 FT., FT.	AIR BORNE TIME TO CLEAR 50 FT., SEC.	AIR BORNE DIST. TO CLEAR 50 FT., FT.	AIR BORNE TIME TO CLEAR 50 FT., SEC.	AIR BORNE DIST. TO CLEAR 50 FT., %	AIR BORNE TIME TO CLEAR 50 FT., %
17,500	1140	6.6	750	4.2	34.2	36.4
18,000	1220	6.8	810	4.4	33.6	35.3
19,000	1410	7.3	950	5.0	32.6	31.5
20,000	1630	8.3	1120	6.0	31.3	27.8

TABLE VI

	WITHOUT JET		WITH JET		REDUCTION DUE TO JET	
GROSS WT. LB.	TOTAL DIST. TO CLEAR 50 FT., FT.	TOTAL TIME TO CLEAR 50 FT., SEC	TOTAL DIST. TO CLEAR 50 FT., FT.	TOTAL TIME TO CLEAR 50 FT., SEC	TOTAL DIST. TO CLEAR 50 FT., %	TOTAL TIME TO CLEAR 50 FT., %
17,500	2680	25.1	1810	17.7	32.5	29.5
18,000	2900	26.2	1960	18.4	32.4	29.8
19,000	3370	28.9	2280	20.0	32.3	30.8
20,000	3950	33.3	2680	22.8	32.2	31.5

the various distances and times tabulated above is plotted against the airplane gross weight in Figs. 42 and 43.

The C.A.A. equipment for recording the A-20A airplane take-off performance made available data on the horizontal and vertical position of the airplane at 1/8 second intervals from the start of the ground run until a height of approximately 50 ft. was reached. From these data the flight path of the airplane after it left the ground and also the variation of the velocity and acceleration with distance can be plotted.

In Figs. 44, 45, and 46 typical flight paths have been plotted for three airplane gross weight conditions with and without auxiliary jet propulsion. The tests plotted in each figure have been chosen for approximately the same airplane gross weights.

For the same tests the variation of air speed and acceleration with distance from the starting point have been plotted in Figs. 47, 48, and 49, and Figs. 50, 51, and 52 respectively.

The flight path curves are seen to be considerably steeper when the jet thrust was acting, however, the acceleration curves show that the excess thrust available was not entirely used to increase the rate of climb of the airplane. An airplane before reaching a steady climbing flight after taking-off passes through a transition phase or "flare." The "flare" is ended when the optimum climbing angle is reached and thereafter the acceleration of the airplane should have a zero value. A study of the flight path curves and acceleration curves shows that the airplane was put into a steady climb before the excess thrust available for lifting was absorbed. Three reasons can be given for not obtaining the optimum angle of climb to clear 50 ft. (1) Since the primary purpose of the flight tests was a study of the operation of the jet installation a detailed schedule for obtaining the optimum performance out of the airplane was not prepared. (2) It was believed advisable, because of the experimental nature of the flight tests, to fly the airplane well above stalling speed to give the pilot an opportunity to level out in case one of the jet units failed. (3) A study of the C.A.A. film showed that in the jet assisted take-offs the landing gear was not completely retracted, with but few exceptions, until the 50 ft. height had been exceeded. In the unassisted take-offs the gear was usually retracted by the time a height of 40 ft. had been reached.

Three flights were made in the air to determine the effect of auxiliary jet propulsion on the performance of the airplane. The first, Test No. 9, was carried out to check the ability of the vertical control surfaces to balance the yaw produced by one jet unit alone delivering 1000 lb. thrust. The others, Tests No. 16 and 38, were made to observe the increase in maximum speed at 5000 ft. and 10,000 ft. resulting from 2000 lb. jet thrust acting for 24 seconds. The results of these tests have been described in Part IV.

At 5000 ft. the indicated air speed increased from 252 m.p.h. to 300 m.p.h. This corresponds to an increase of 19% in maximum speed. At 10,000 ft. the indicated air speed increased from 239 m.p.h. to 280 m.p.h. or 17.2%.

The airplane did not reach the maximum speed possible by the addition of 2000 lb. thrust due to the fact that the duration of the jet thrust was limited to 24 seconds. It can be seen that the airplane was still accelerating when the jet thrust ceased from the plot of indicated air speed against time in Fig. 53 for the flight at 10,000 ft.

VI. COMPARISON OF EXPERIMENTAL RESULTS WITH THEORETICAL PREDICTIONS OF EFFECT OF AUXILIARY JET THRUST

An aerodynamic analysis of take-off and initial climb of aircraft as affected by auxiliary jet propulsion has been carried out by Millikan and Stewart in Reference 6. The analysis is based on the studies of land plane take-off made by E. P. Hartman in N.A.C.A., T.N. 557. A simpler method for predicting only the effect of a constant auxiliary thrust on the reduction of ground run of aircraft using the same basic assumptions has been proposed by Fischer and Coffman. This method consists of taking the fundamental equation of motion given in Reference 6 and replacing the excess thrust delivered by the propeller, which normally varies during the take-off run, by an average value. The average excess thrust is taken as the ratio of the kinetic energy of the airplane at take-off to the ground run distance. A chart prepared according to this assumption is reproduced in Fig. 54.

In the following discussion these notations will be used:

A = Initial accelerating thrust for the normal airplane, lb.

B = Thrust decrement coefficient for the normal airplane.

C_1 = Static thrust of propeller, lb.

F = Thrust delivered by jet units, lb.

g = Acceleration due to gravity, ft. per sec.^{2}

h = Altitude, ft.

S_o = Take-off distance for normal airplane, ft.

S_c = Horizontal distance to climb to height, h, for normal airplane.

t = Time, sec.

V = Velocity, ft. per sec.

V_{TO} = Take-off velocity for normal airplane, ft. per sec.

W = Normal airplane gross weight, lb.

$\alpha = F/A$

$\lambda = \sqrt{\frac{B}{A}}\, V_{TO}$

μ = Coefficient of rolling friction.

$(\ )'$ = Refers to jet assisted take-off.

$(\ )_\omega$ = Refers to condition with overload.

$(\ )_c$ = Refers to climb after take-off.

1. Effect of Auxiliary Jet Propulsion on Take-off Distance

From Reference 6 the take-off distance for any load condition with auxiliary jet propulsion is given by:

$$S'_{o_\omega} = -\beta \frac{W}{2gB} \log\left(1 - \frac{\beta\lambda^2}{1+\alpha}\right) \qquad (1)$$

and the relative saving in distance due to the auxiliary thrust can be determined from the relation:

$$\frac{S_{o_\omega} - S'_{o_\omega}}{S_{o_\omega}} = 1 - \frac{\log\left(1 - \frac{\beta\lambda^2}{1+\alpha}\right)}{\log(1 - \beta\lambda^2)} \qquad (2)$$

According to the Fischer-Coffman approximate method the take-off distance for any load condition with auxiliary jet propulsion is given by:

$$S_{o_\omega}' = \frac{S_{o_\omega}}{\frac{2g}{\beta W}\frac{S_{o_\omega}}{V_{TO_\omega}^2}F+1} \qquad (3)$$

and the relative saving in distance has the form:

$$\frac{S_{o_\omega}-S_{o_\omega}'}{S_{o_\omega}} = 1 - \frac{1}{\frac{2g}{\beta W}\frac{S_{o_\omega}}{V_{TO_\omega}^2}F+1} \qquad (4)$$

The performance factors B and λ in equation (1) can be determined for the normal A-20A on the basis of the experimentally measured take-off distance. The normal gross weight will be taken as 17,500 lb.

$B = 0.09$

$\lambda = 0.635$

The factor A, the initial accelerating thrust for the normal airplane, is defined as the static propeller thrust minus the ground friction. (It is assumed that $\mu = 0.02$)

$$A = C_1 - \mu W = 5925 - 0.02 \times 17{,}500 = 5575 \text{ lb.}$$

$$\alpha = \frac{F}{A} = \frac{2000}{5575} = 0.36$$

In Table VII the percent reduction due to auxiliary jet thrust in take-off distance for different gross weights is compared with the values calculated from equations (2) and (4).

TABLE VII

GROSS WEIGHT LB.	EXPERIMENTAL REDUCTION IN TAKE-OFF DIST.	MILLIKAN-STEWART METHOD %	FISCHER-COFFMAN APPROXIMATE METHOD %
17,500	29.9	31.3	30.3
18,000	31.1	32.0	31.2
19,000	32.1	32.5	31.9
20,000	32.3	33.0	32.6

From Table VII it can be seen that the percent reduction obtained in the flight tests agrees exceedingly well with both methods of predicting the effect of auxiliary jet thrust. The advantage of the Millikan-Stewart method lies in the possibility of calculating the reduction in take-off run due to auxiliary jet thrust for any overload condition when the normal take-off distance is known for only one gross weight. The approximate calculation, on the other hand, required a knowledge of the take-off distance for each overload condition before the corresponding reduction due to auxiliary jet thrust can be determined. Furthermore, the Fischer-Coffman method is suitable only for predicting the reduction in take-off distance.

2. Effect of Auxiliary Jet Thrust on Take-off Time

From Reference 6 the take-off time for any load condition with auxiliary jet propulsion is given by:

$$t'_{o_w} = \frac{\beta W}{2g\sqrt{(1+\alpha)BA}} \left(\frac{1+\sqrt{\frac{\beta}{1+\alpha}\frac{B}{A}}\,V_{TO}}{1-\sqrt{\frac{\beta}{1+\alpha}\frac{B}{A}}\,V_{TO}} \right) \tag{5}$$

and the relative saving in time by:

$$\frac{t_{o_w}-t'_{o_w}}{t_{o_w}} = 1-\frac{\sqrt{BA}}{\sqrt{(1+\alpha)BA}}\;\frac{\log\left(\frac{1+\sqrt{\frac{\beta}{1+\alpha}\frac{B}{A}}\,V_{TO}}{1-\sqrt{\frac{\beta}{1+\alpha}\frac{B}{A}}\,V_{TO}}\right)}{\log\left(\frac{1+\sqrt{\beta\frac{B}{A}}\,V_{TO}}{1-\sqrt{\beta\frac{B}{A}}\,V_{TO}}\right)} \tag{6}$$

In Table VIII the experimentally observed percent reduction due to auxiliary jet thrust in take-off time for different gross weights is compared with the values calculated from equation (6). The factors in equation (6) have the same numerical values as before.

TABLE VIII

GROSS WEIGHT, LB.	EXPERIMENTAL REDUCTION IN TAKE-OFF TIME, %	MILLIKAN-STEWART METHOD, %
17,500	27.0	30.2
18,000	28.0	30.4
19,000	30.5	30.7
20,000	33.1	31.0

The reduction in take-off time obtained experimentally agrees with the calculated results very closely.

3. Effect of Auxiliary Jet Thrust on Distance to Climb to a Height h

From Reference 6 the horizontal distance required to climb to a height h with auxiliary jet propulsion is given by the relation:

$$S'_{c_\omega} = \frac{\beta W h}{A} \frac{1}{(1-\varepsilon_\omega \lambda_c^2) + \alpha} \qquad (7)$$

The factors ε_ω and λ_c are defined and discussed in Reference 6. The value of the term $(1-\varepsilon_\omega \lambda_c^2)$ can be determined from the experimentally measured horizontal distance required to climb to 50 ft. for the case of the normal airplane for each gross weight condition. The values obtained are shown in Table IX.

TABLE IX

GROSS WEIGHT, LB.	$(1-\varepsilon_\omega \lambda_c^2)$
17,500	0.157
18,000	0.135
19,000	0.122
20,000	0.111

The relative saving in horizontal distance required, achieved through the use of jet thrust, is given by:

$$\frac{S_{c_\omega} - S'_{c_\omega}}{S_{c_\omega}} = 1 - \frac{(1-\varepsilon_\omega \lambda_c^2)}{(1-\varepsilon_\omega \lambda_c^2) + \alpha} \qquad (8)$$

In Table X the percent reduction in the climbing distance required to clear 50 ft. obtained from equation (8) is compared with the results of the flight tests.

TABLE X

GROSS WEIGHT, LB.	EXPERIMENTAL REDUCTION IN HORIZONTAL DISTANCE TO CLEAR 50 FT. %	MILLIKAN-STEWART METHOD, %
17,500	34.2	69.6
18,000	33.6	72.1
19,000	32.6	74.7
20,000	31.3	76.4

The experimentally determined reduction in air borne distance to clear 50 ft. with jet thrust is seen in the table to be much smaller than theoretical analysis indicates should be expected. The experimental reduction is not as large as possible since the excess thrust made available by the jet units was not utilized completely for increasing the angle of climb. The probable reasons for not absorbing the excess thrust have been mentioned in connection with the discussion of the flight path curves.

On the other hand, the reduction predicted by the theoretical analysis is definitely optimistic. In the Millikan-Stewart analysis the transition phase from horizontal motion to flight in a steady climb was neglected. This assumption is valid only when, with auxiliary jet thrust, the horizontal distance traversed during the "flare" is small compared to the horizontal distance covered in a steady climb.

4. Effect of Auxiliary Jet Thrust on the Time to Climb to a Height h

From Reference 6 the time required to climb to a height h with auxiliary jet propulsion is given by the relation:

$$t'_{c_\omega} = \frac{\sqrt{\beta} W h}{A V_{TO}} \frac{1}{(1-\varepsilon_\omega \lambda_c^2)+\alpha} \tag{9}$$

The relation for the relative saving in time is identical to equation (8).

$$\frac{t_{c_\omega} - t'_{c_\omega}}{t_{c_\omega}} = 1 - \frac{(1-\varepsilon_\omega \lambda_c^2)}{(1-\varepsilon_\omega \lambda_c^2)+\alpha} \tag{10}$$

The percent reduction in time to clear a height of 50 ft. with auxiliary jet propulsion obtained in the flight tests is compared with the values calculated from equation (10) in Table XI.

TABLE XI

GROSS WEIGHT, LB.	EXPERIMENTAL REDUCTION IN TIME TO CLEAR 50 FT., %	MILLIKAN-STEWART METHOD, %
17,500	36.4	69.6
18,000	35.3	72.1
19,000	31.5	74.7
20,000	27.8	76.4

The remarks made in connection with the discrepancy of the flight test results with the calculated reduction in horizontal distance required to clear 50 ft. apply also to the discrepancy apparent in Table XI.

5. Effect of Auxiliary Jet Thrust on the Total Distance Required to Reach a Height of 50 ft.

To compare the effect of jet thrust on the total distance required from the beginning of the ground run to the point 50 ft. was cleared with the theoretically predicted value the unassisted distances given in Tables IV and V are reduced in accordance with the percentages given in Tables VII and X. The results are compared in Table XII.

TABLE XII

GROSS WEIGHT, LB.	EXPERIMENTAL REDUCTION IN TOTAL DISTANCE, %	MILLIKAN-STEWART METHOD, %
17,500	32.5	47.6
18,000	32.4	48.9
19,000	32.3	50.0
20,000	32.2	50.8

Since the reduction in take-off ground run obtained in the flight tests agrees with the calculated results (Cf. Table VII) the discrepancy in the reduction of total distance required to clear 50 ft. can be accounted for by the much larger distance taken during the air borne portion of the take-off as is apparent in Table X.

6. Effect of Auxiliary Jet Thrust on the Total Time Required to Reach a Height of 50 ft.

Using a procedure similar to that described for the values given in Table XII the results shown in Table XIII were obtained.

TABLE XIII

GROSS WEIGHT, LB.	EXPERIMENTAL REDUCTION IN TOTAL TIME, %	MILLIKAN-STEWART METHOD, %
17,500	29.5	40.8
18,000	29.8	41.3
19,000	30.8	41.8
20,000	31.5	42.2

The discrepancy between the flight tests and the calculated results in Table XIII can be accounted for by the much longer time taken during the air borne portion of the take-off to clear 50 ft. as is apparent in Table XI.

CONCLUSION

The flight tests of the A-20A airplane described and analyzed in this report successfully accomplished the objectives that had been set up when the investigations at the Air Corps Jet Propulsion Research Project indicated that a 1000 lb. thrust liquid propellant jet unit was ready for attachment on a service type aircraft. As pointed out in Part III the primary purpose of the flight tests was to obtain information on problems of installation and operation of jet units on aircraft. In conjunction with these studies performance data were obtained so that the effect of auxiliary jet propulsion could be determined.

The analysis of the flight test data in Part VI shows that the reduction in take-off distance and time agrees with theoretically predicted values very closely. The experimental reduction in air borne distance to clear a height of 50 ft., however, was only approximately one half the amount that theory indicated should be expected. The probable reasons for this discrepancy have been discussed in Part V. Additional flight tests are necessary to determine the optimum reduction in distance to clear 50 ft. that can be obtained from auxiliary jet propulsion. Flight tests for this purpose should be made with service type jet units incorporating improvements based on the experience already gained.

Auxiliary jet propulsion when used to improve the take-off performance of aircraft can either reduce the distance required during the take-off phases for the normal gross weight condition, or hold the normal take-off distance when large overloads have to be carried. The tactical situation will determine for which purpose the advantages of jet propulsion should be used.

When jet propulsion equipment is utilized only during the take-off phase of aircraft flight the question arises as to the penalty that might be paid in carrying the empty weight of the equipment. At the present stage of development the ratio of jet thrust to empty weight has a value of approximately 6.0. For the case of the A-20A the installation of jet equipment for 2000 lb. thrust would necessitate carrying a dead weight of 335 lb.

It has also been proposed to design the jet equipment to fit inside a streamlined body that could be attached externally to the aircraft and then dropped when the propellants were exhausted. In this way the empty dead weight would not hinder the flight performance of the aircraft. Furthermore, the enemy can be prevented from capturing the jet equipment on shot down aircraft and learning the design secrets. The disadvantages of the dropable type of installation lie in the greater effort that will probably be expended in servicing and maintenance and in the reduction of excess thrust delivered by the jet units due to drag of the externally mounted body.

For the case of the assisted take-off of heavily loaded aircraft the weight of a jet installation can easily be over-emphasized. This can be pointed out most clearly by means of the curves drawn in Figs. 55 and 56. In Fig. 56 the influence of φ, the ratio of jet thrust to the full weight of the jet installation, on the useful overload that can be lifted within the normal take-off distance is shown for a particular case. It is apparent that the useful overload increases rapidly at first as φ increases, however, after φ reaches a value of 5 the gain in additional overload is small.

The advantage of using auxiliary jet thrust supplied by an installation whose $\varphi = 3$ when full and $\varphi = 6$ when empty is also clear. For the case considered the airplane would take-off in the normal distance with a useful overload of 4000 lb. at the cost of carrying an empty weight of 670. The necessity of dropping the empty jet installation must be guided by the effect of its weight on the flight performance of the airplane.

Due to the limited time available for the A-20A flight tests comprehensive studies of the effect of auxiliary jet thrust on high speed and rate of climb were not made. Tests should be carried out with an installation delivering jet thrust for a period of the order of one minute so that equilibrium flight conditions can be reached.

During the flight tests, heat radiated from the jet blasts caused the fabric covering on the elevators to loosen and wrinkle. This difficulty was eliminated by treating the surfaces with special paints. The difficulty could probably be overcome by directing the jet blast downward. In this connection it is understood that in England the jet has been directed downward with beneficial results also on the take-off performance of the aircraft. An analysis of the effect of the jet angle on the take-off performance should be undertaken.

REFERENCES

1. Malina, F. J. and Parsons, J. W., "Results of Flight Tests of the Ercoupe Airplane with Auxiliary Jet Propulsion Supplied by Solid Propellant Jet Units," Air Corps Jet Propulsion Research, GALCIT Project No. 1, Report No. 9, 1941.

2. Summerfield, M., Powell, W. B., and Crofut, E. G., "Development of a Liquid Propellant Jet Unit and Its Operation on an A-20A Airplane," Air Corps Jet Propulsion Research, GALCIT Project No. 1, Report No. 13, 1942.

3. Martin, V. J., "Airplane Take-off Performance," California Institute of Technology, Masters Thesis, 1936.

4. Malina, F. J., Parsons, J. W., and Forman, E. S., "Final Report for 1939-40," Air Corps Jet Propulsion Research, GALCIT Project No. 1, Report No. 3, 1940.

5. Summerfield, M. and Forman, E. "Progress Report on the Development of a Liquid-Propellant Jet Motor," Air Corps Jet Propulsion Research, GALCIT Project No. 1, Report No. 10, (Preliminary), 1941.

6. Millikan, C. B. and Stewart, H. J. "Aerodynamic Analysis of Take-off and Initial Climb as Affected by Auxiliary Jet Propulsion," Air Corps Jet Propulsion Research, GALCIT Project No. 1, Report No. 5, 1941.

Fig. 1 — Front quarter view of the A-20A airplane.

Fig. 2 -- Rear quarter view of the A-20A airplane.

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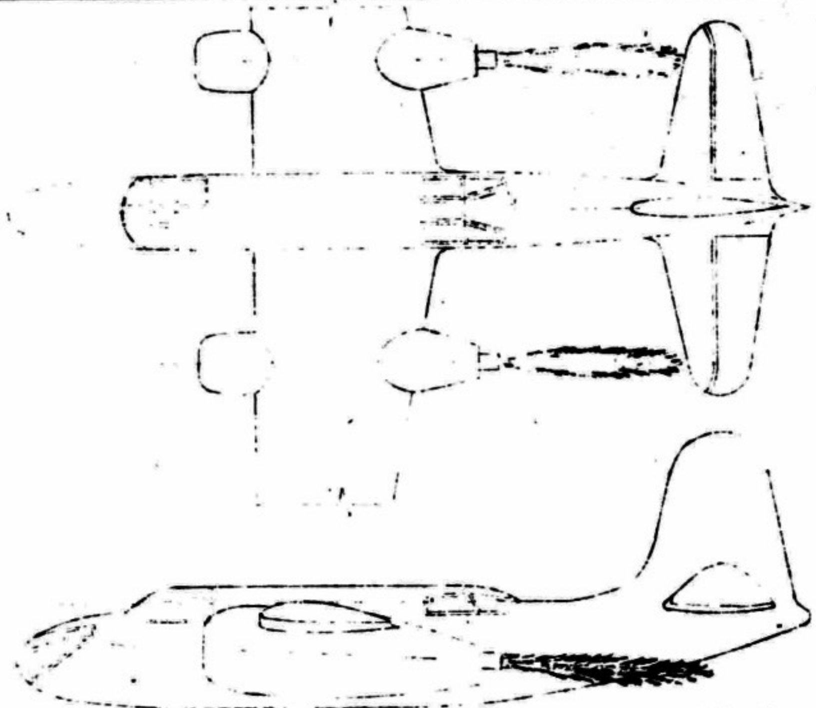
FIG 3

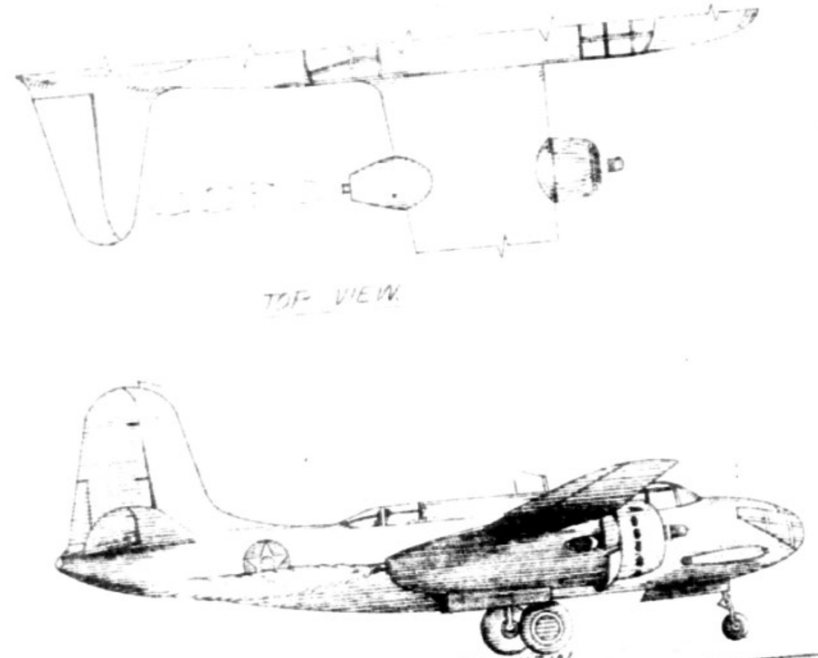


MATERIAL	FINISH	HEAT TREAT	DRAFTSMAN	CHECKED	APPROVED	ENGINEER	TOLERANCES ± .010 OR $\frac{1}{64}$ UNLESS OTHERWISE NOTED
			[illegible]		E.C. [illegible] MAY 23 1942		$\frac{1}{36}$" = 1" SCALE
GUGGENHEIM AERONAUTICAL LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY			APPROXIMATE JET PATTERN				1-256-LI-21
			NAME				DRAWING NO.

CONFIDENTIAL

GALCIT PROJECT NO 1
REPORT NO 12

FIG. 4



THREE QUARTER SIDE VIEW

			5/21/42		E.G. CROFUT		TOLERANCES ±.010 DREG UNLESS OTHERWISE NOTED
			[signature]		5/21/42		$\frac{1}{95}$" = 1"
MATERIAL	FINISH	HEAT TREAT	DRAFTSMAN	CHECKED	APPROVED	ENGINEER	SCALE
GUGGENHEIM AERONAUTICAL LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY			APPROXIMATE JET PATTERN				1-256-L1-21
			NAME				DRAWING NO.

CONFIDENTIAL

Fig. 5 -- Major P. H. Dane, pilot, and B. M. Forman, jet operator, during the flight tests.

Fig. 6 -- Personnel in charge of flight tests, from right to left: Dr. Th. von Karman, Major P. H. Dane, W. B. Powell, Dr. F. J. Malina, and Dr. M. Summerfield.

Fig. 7 -- Flight test personnel.

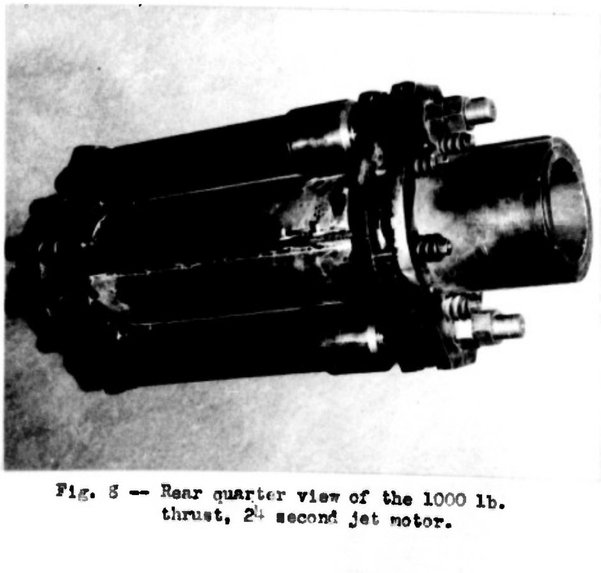
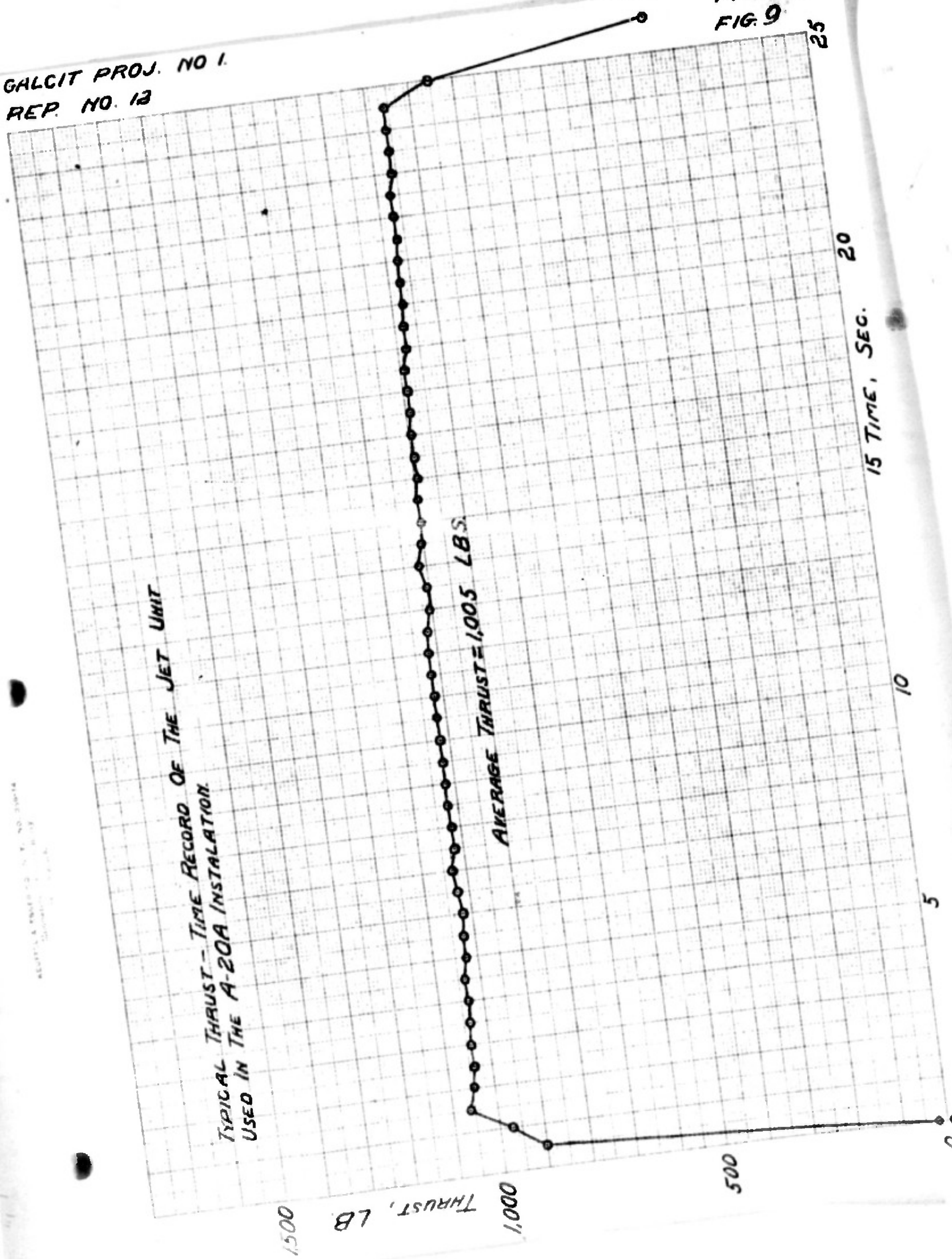


Fig. 8 -- Rear quarter view of the 1000 lb. thrust, 24 second jet motor.

FIG. 9



TYPICAL THRUST - TIME RECORD OF THE JET UNIT USED IN THE A-20A INSTALATION.

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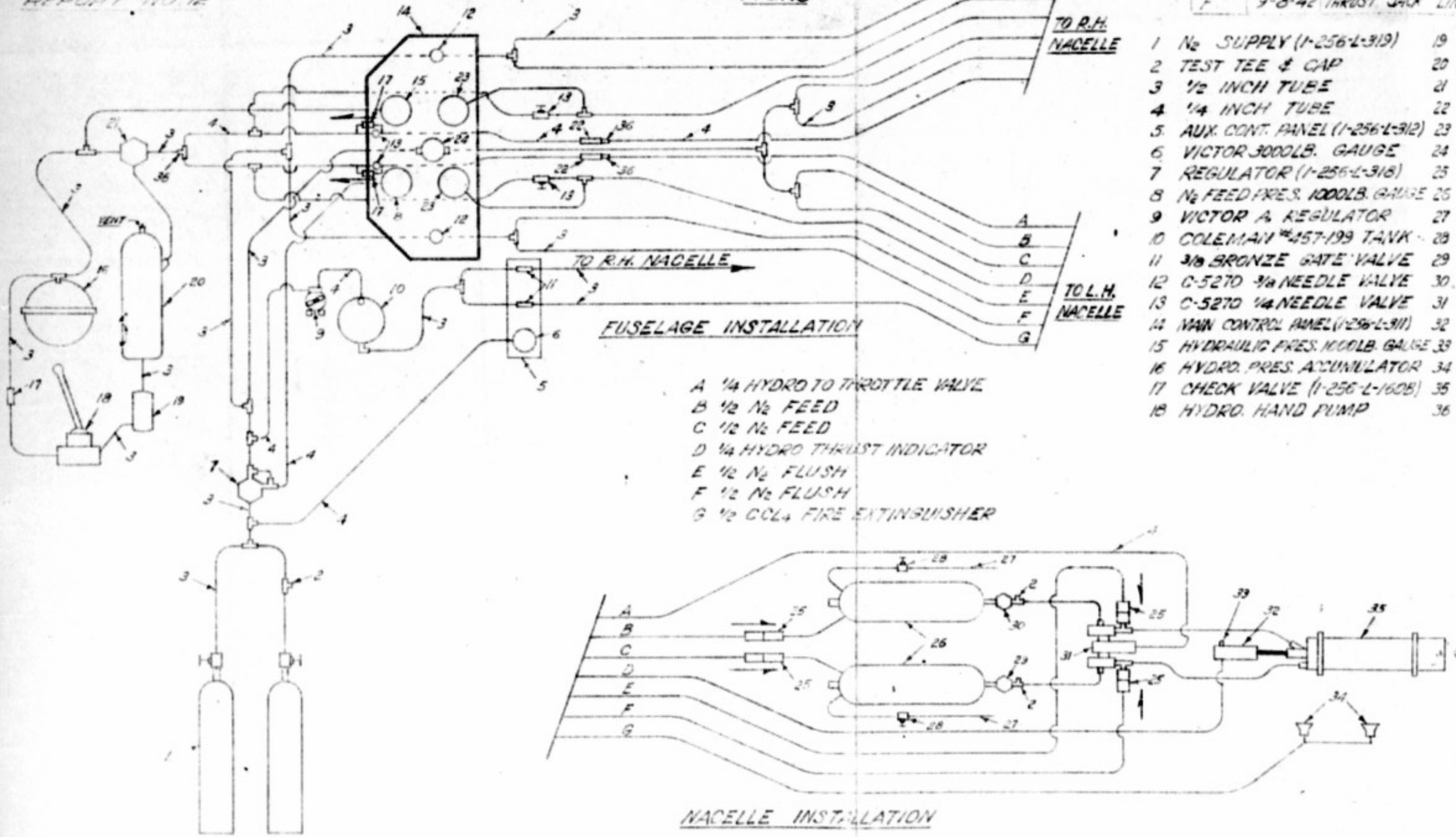
FIG. 10

LET	DATE	CHANGE	BY	APP
F	9-8-42	THRUST JACK LINE CORRECTED	Stiven	E.R.



1 N_2 SUPPLY (1-256-L-319)
2 TEST TEE & CAP
3 1/2 INCH TUBE
4 1/4 INCH TUBE
5 AUX. CONT. PANEL (1-256-L-312)
6 VICTOR 3000LB. GAUGE
7 REGULATOR (1-256-L-318)
8 N_2 FEED PRES. 1000LB. GAUGE
9 VICTOR A. REGULATOR
10 COLEMAN #457-199 TANK
11 3/8 BRONZE GATE VALVE
12 C-5270 3/8 NEEDLE VALVE
13 C-5270 1/4 NEEDLE VALVE
14 MAIN CONTROL PANEL (1-256-L-311)
15 HYDRAULIC PRES. 1000LB. GAUGE
16 HYDRO. PRES. ACCUMULATOR
17 CHECK VALVE (1-256-L-1608)
18 HYDRO. HAND PUMP
19 HYDRO. OIL FILTER
20 HYDRO. OIL RESERVOIR
21 AIRCRAFT ACCESSORIES #6203S VALVE
22 #74E CHECK (1-256-L-313)
23 THRUST GAUGE 2000LB.
24 N_2 MAIN VALVE (1-256-L-323)
25 DOUBLE CHECK VALVE (1-256-L-317)
26 PROPELLANT TANK (2-256-L-173)
27 VENT LINE-DISCHARGE FREE
28 VENT VALVE (S 5280 1/4)
29 ACID GATE VALVE (18840 1/2)
30 FUEL GATE VALVE (#14 1/2)
31 THROTTLE VALVE (1-256-L-239)
32 THRUST JACK (2-256-L-294)
33 BLEED CAP
34 PASADENA SPRINKLER HEAD
35 MOTOR ASS'Y (2-256-L-274)
36 STRAINER (1-256-L-314)

A 1/4 HYDRO TO THROTTLE VALVE
B 1/2 N_2 FEED
C 1/2 N_2 FEED
D 1/4 HYDRO THRUST INDICATOR
E 1/2 N_2 FLUSH
F 1/2 N_2 FLUSH
G 1/2 CCL_4 FIRE EXTINGUISHER

NOTE:
ARROW ——► INDICATES DIRECTION OF FLOW THRU CHECK VALVE

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MATERIAL	FINISH	HEAT TREAT	DRAFTSMAN	CHECKED	APPROVED	ENGINEER	TOLERANCES ± .010 OR 1/64 UNLESS OTHERWISE NOTED
			Stiven 5-15-42	E.G. CROFUT MAY 16 1942	E.G. CROFUT MAY 16 1942		
GUGGENHEIM AERONAUTICAL LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY			NAME: SCHEMATIC DIAGRAM A-20A INSTALLATION				DRAWING NO.: 2-256-L1-28

F

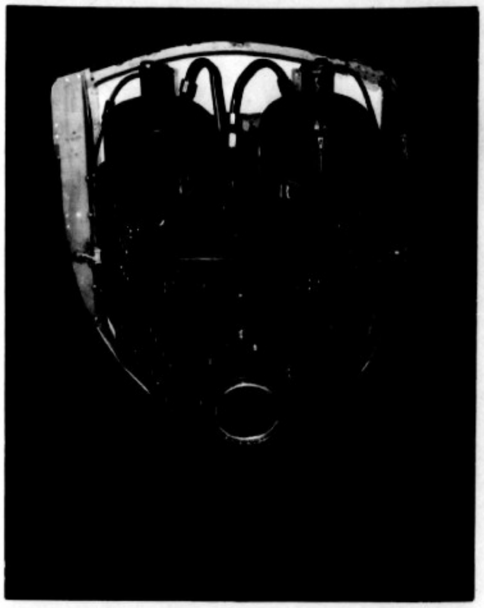

Fig. 11 -- End view of the jet unit installed on the airplane.

Fig. 12 -- Side view of the jet unit installed on the airplane.

Fig. 13 — Side view of jet unit installed in the nacelle cone with the cover in place.

Fig. 14 — Rear view of the A-20A airplane showing exhaust nozzles protruding from the nacelle tail cones.

Fig. 15 -- Nitrogen tanks mounted in the forward bomb bay.

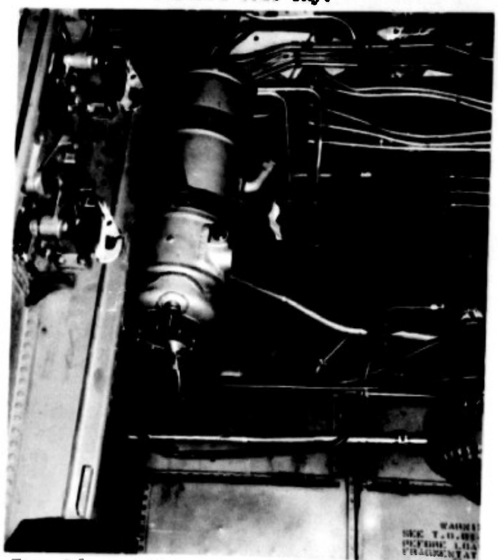

Fig. 16 -- Hydraulic system in rear bomb bay for operating the jet propellant throttle valves.

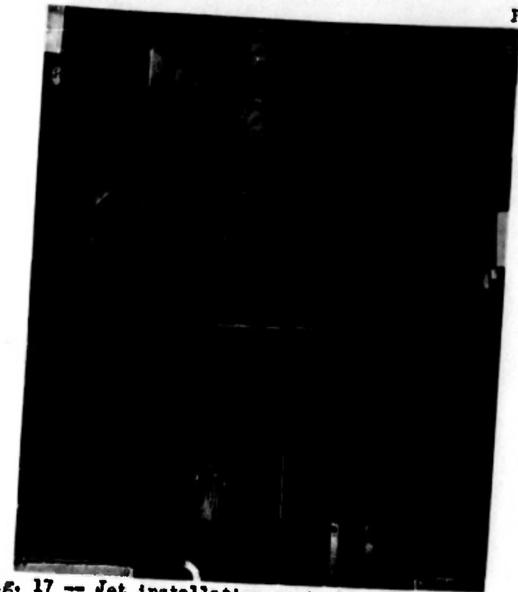

Fig. 17 -- Jet installation controls and instrument panel in rear gunner's cockpit.

Fig. 18 -- Setup for measuring the static thrust of the airplane propellers.

Fig. 19 -- View of gage used to measure static thrust of propellers.

Fig. 20 -- First operation of the jet units with the airplane held stationary.

Fig. 21 — Water test to determine cause of low rate of propellant flow from right jet unit.

Fig. 22 — View of the A-20A with jet units operating at the start of the taxi run.

Fig. 23 — View of yaw test in flight.

Fig. 24 — A-20A about to leave ground on first take-off assisted by auxiliary jet propulsion.

Fig. 25 — Elevator fabric loosened by radiant heat from jet blast.

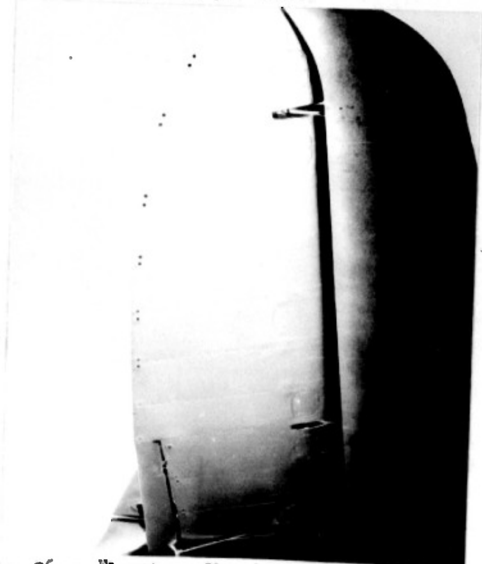

Fig. 26 — Elevator after heat resistant treatment applied.

Fig. 27 -- A-20A taking-off without auxiliary jet propulsion.

Fig. 28 -- Assisted take-off during ground run.

Fig. 29 — Assisted take-off during ground run. Side view showing size of jet blast.

Fig. 30 — A-20A at start of climb assisted by jet thrust.

Fig. 31 — Front view of A-20A in climb assisted by jet thrust.

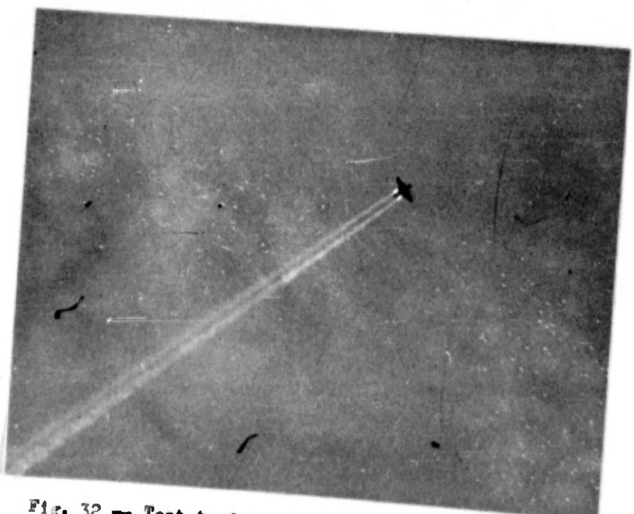

Fig. 32 — Test to determine effect of auxiliary jet thrust on high speed at 10,000 ft.

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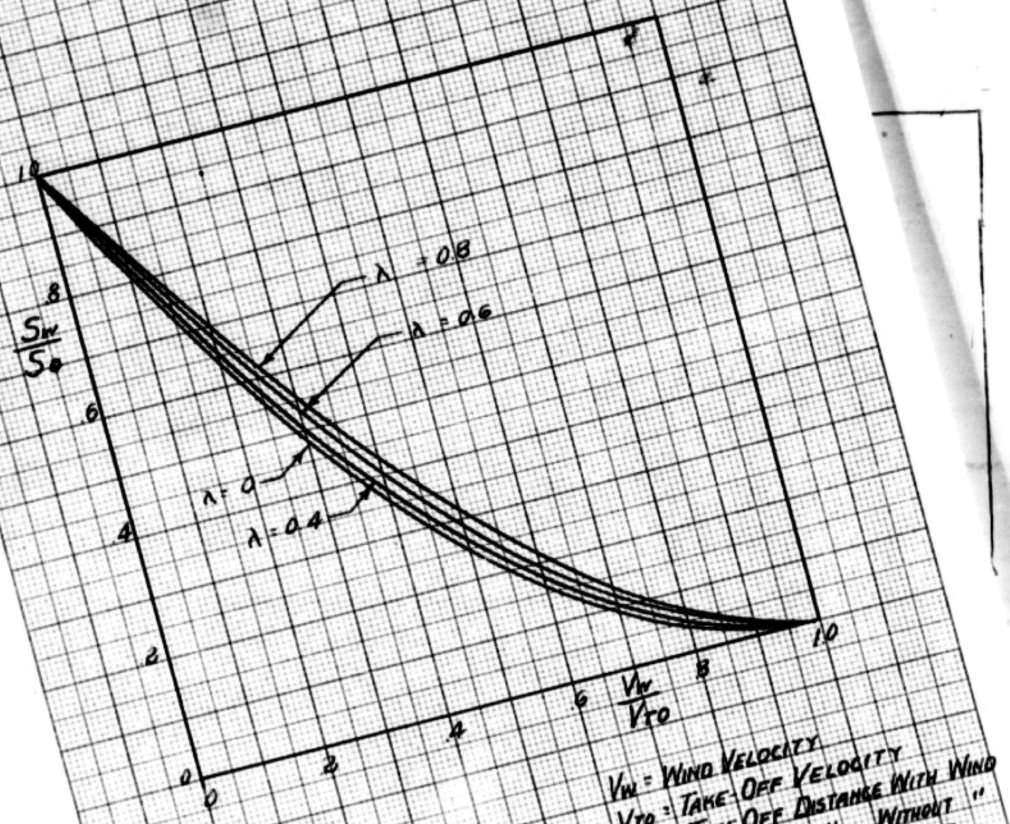
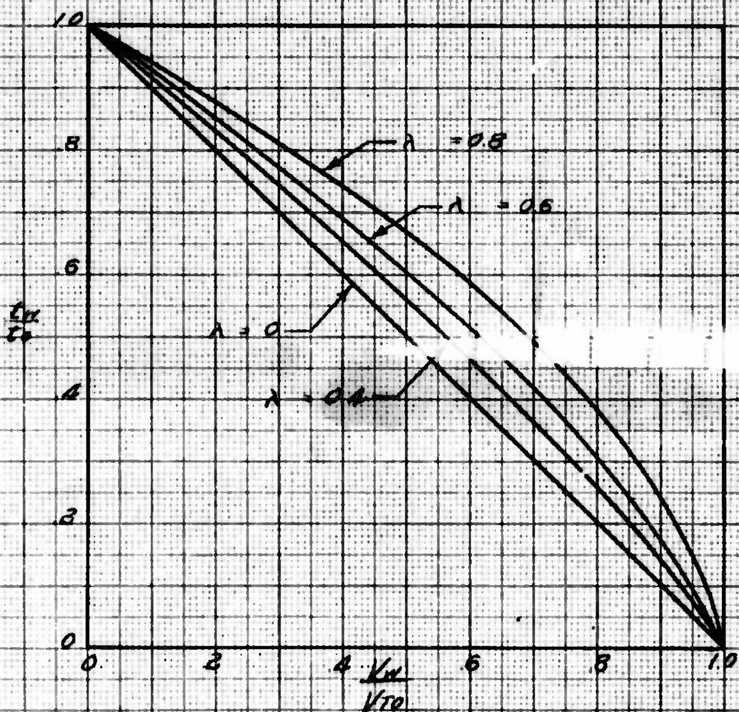
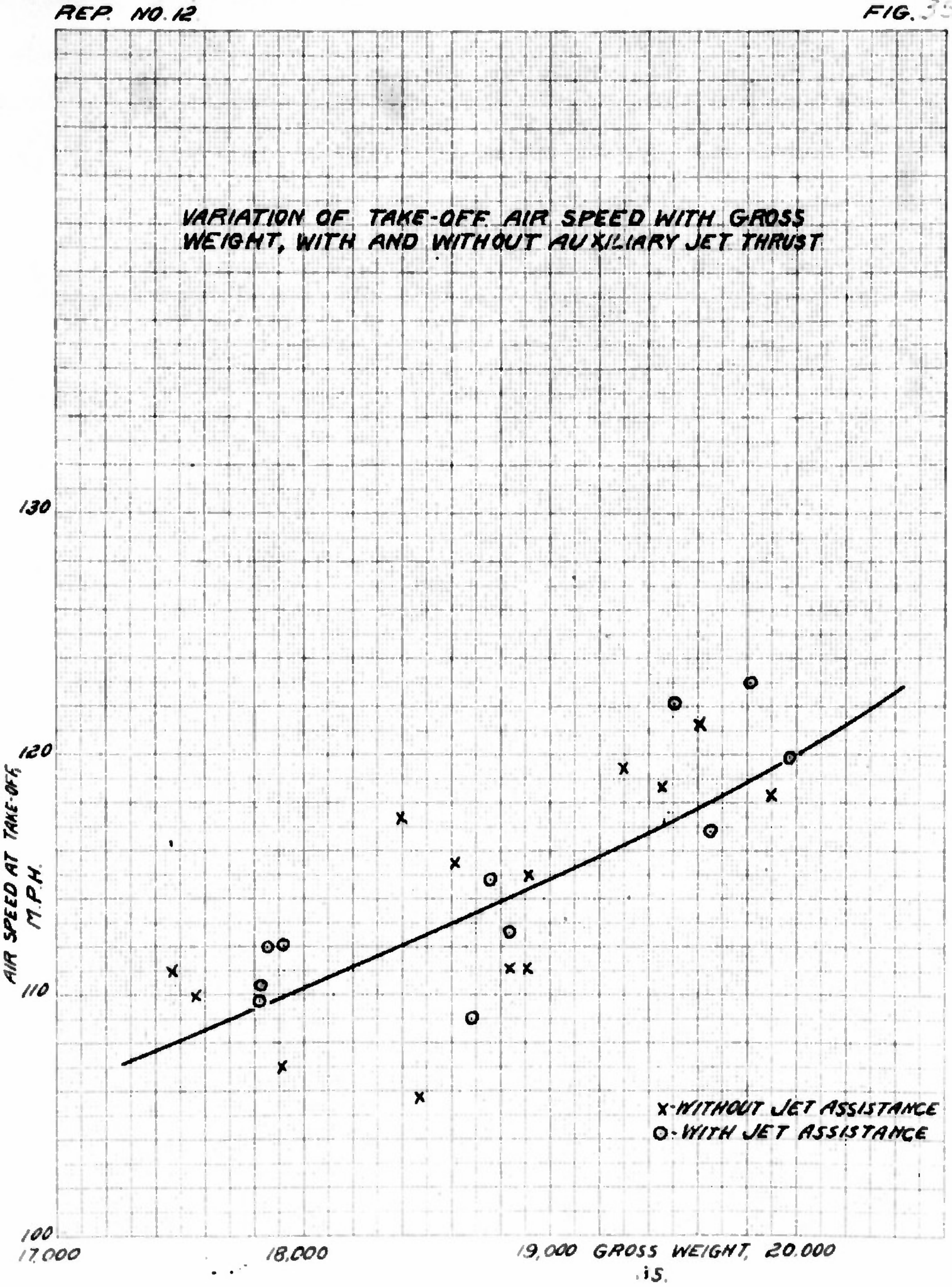


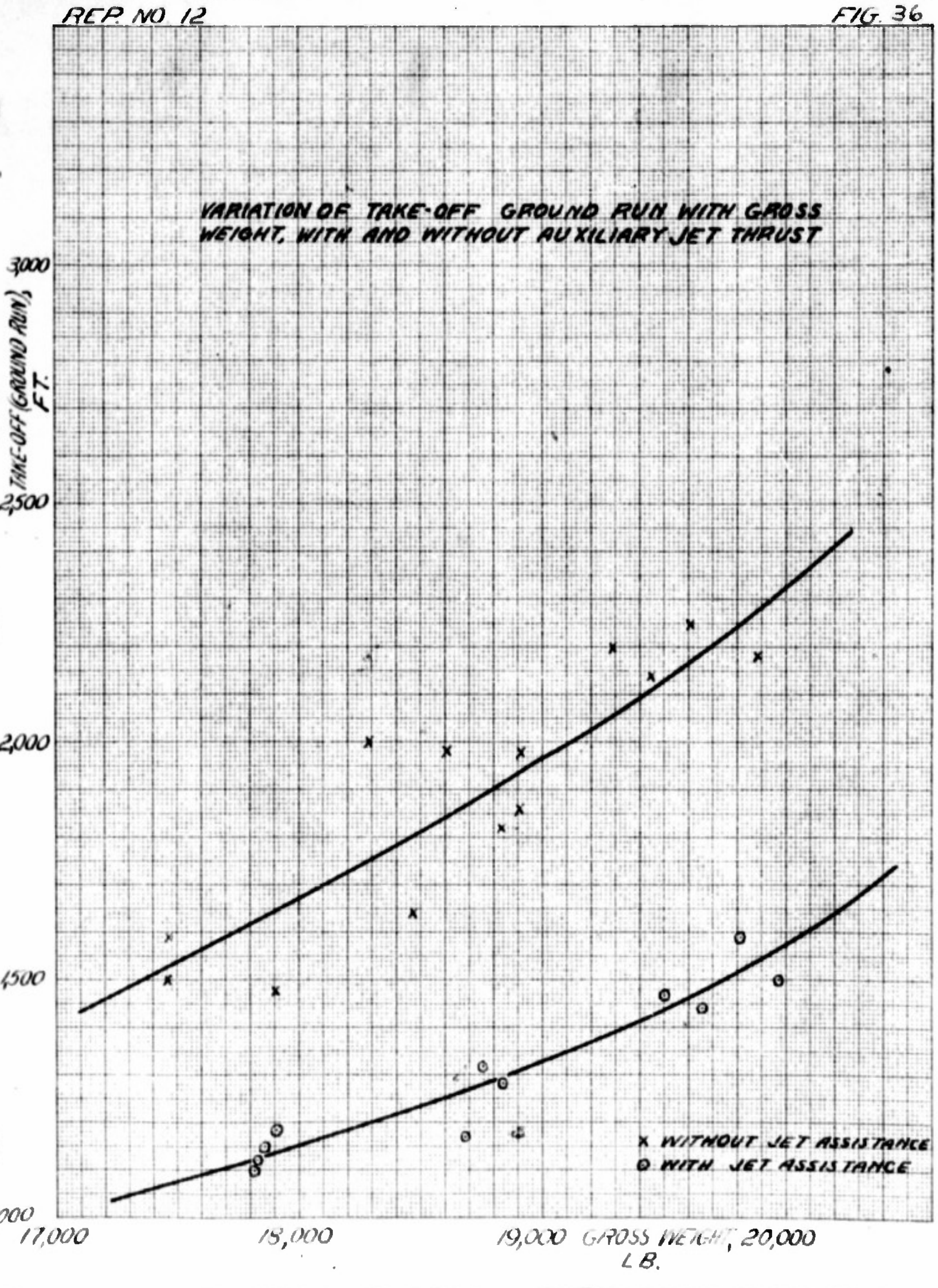
EFFECT OF WIND ON TAKE-OFF DISTANCE

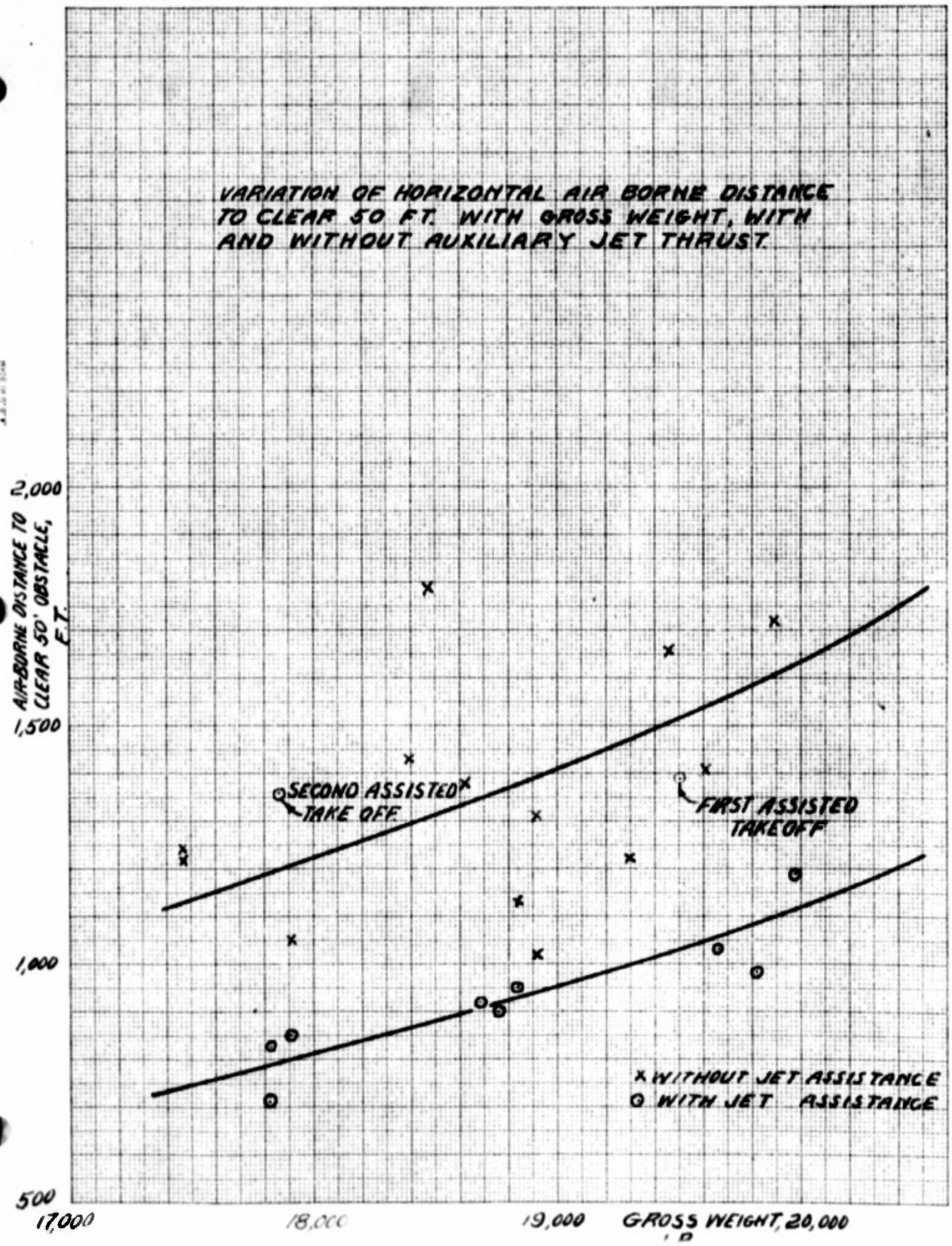


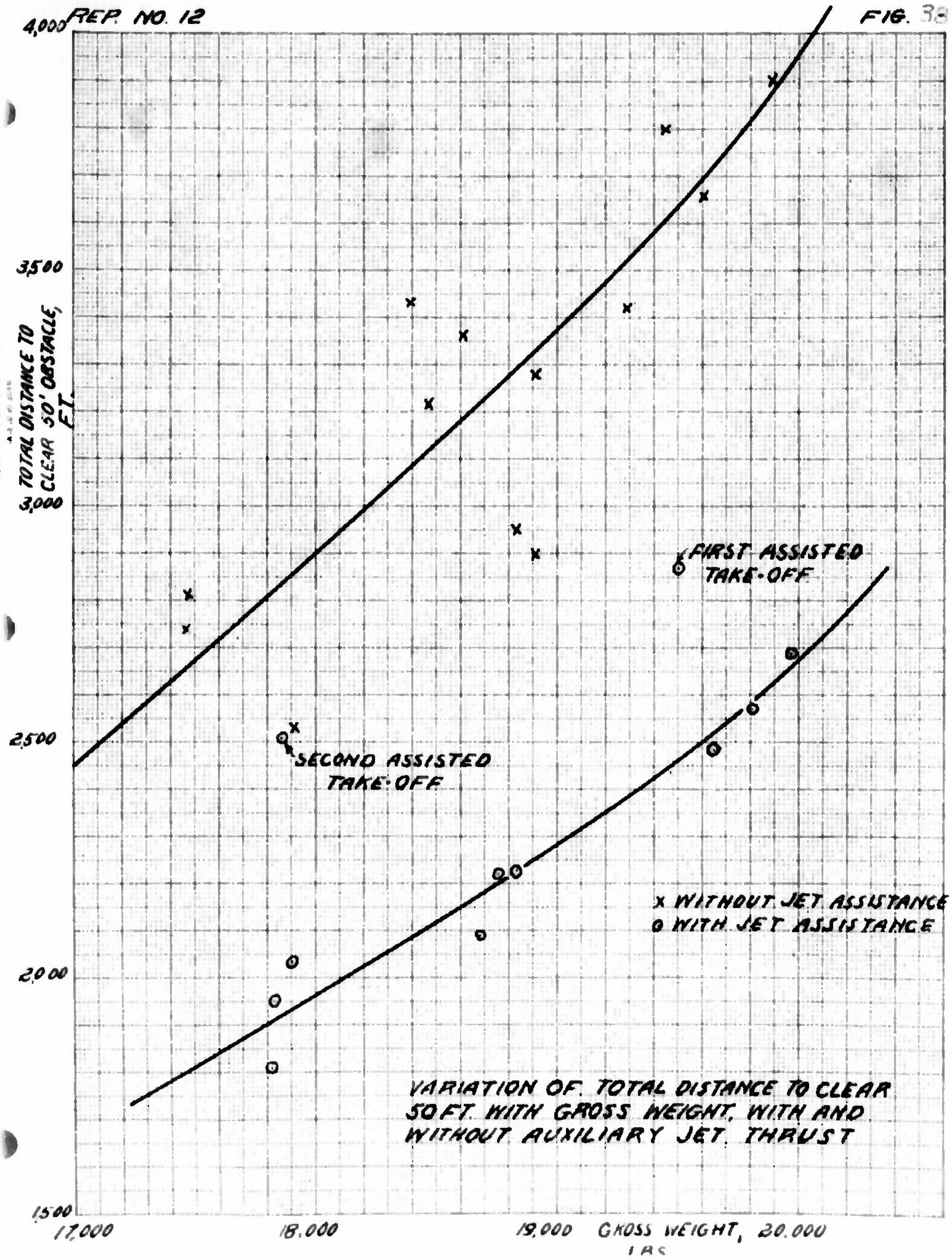
V_W = WIND VELOCITY
V_{TO} = TAKE-OFF VELOCITY
t_W = TAKE-OFF TIME WITH WIND
t_o = " " " WITHOUT "
λ IS DEFINED IN PART VI

EFFECT OF WIND ON TAKE-OFF TIME

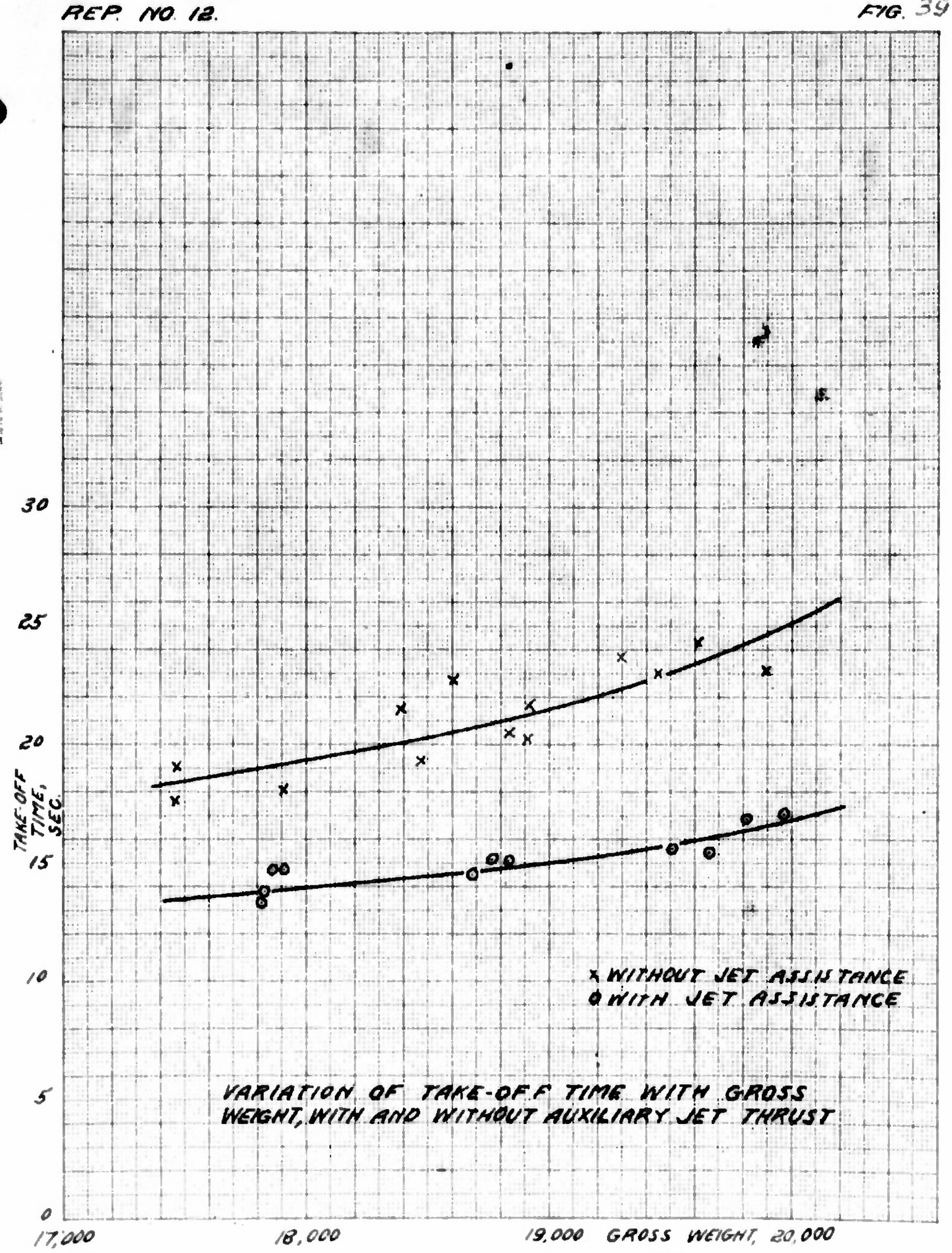

VARIATION OF TAKE-OFF AIR SPEED WITH GROSS WEIGHT, WITH AND WITHOUT AUXILIARY JET THRUST
AIR SPEED AT TAKE-OFF, M.P.H.
130
120
110
100
17,000
18,000
19,000
20,000
GROSS WEIGHT, lbs.
x-WITHOUT JET ASSISTANCE
o-WITH JET ASSISTANCE


VARIATION OF TAKE-OFF GROUND RUN WITH GROSS WEIGHT, WITH AND WITHOUT AUXILIARY JET THRUST
TAKE-OFF (GROUND RUN), FT.
3,000
2,500
2,000
1,500
1000
17,000
18,000
19,000
GROSS WEIGHT, LB.
20,000
× WITHOUT JET ASSISTANCE
⊙ WITH JET ASSISTANCE

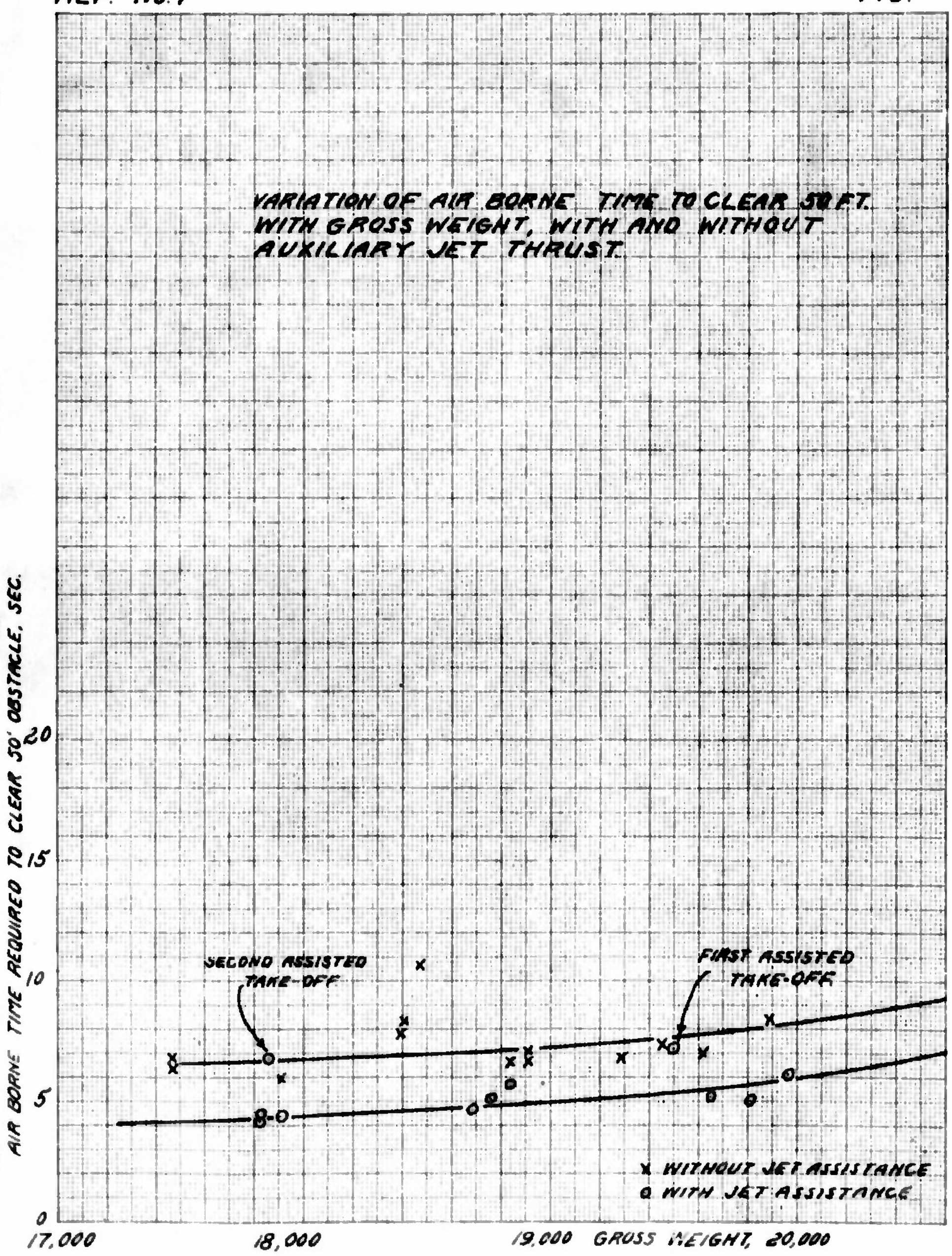

VARIATION OF HORIZONTAL AIR BORNE DISTANCE TO CLEAR 50 FT. WITH GROSS WEIGHT, WITH AND WITHOUT AUXILIARY JET THRUST
AIR-BORNE DISTANCE TO CLEAR 50' OBSTACLE, F.T.
2,000
1,500
1,000
500
17,000
18,000
19,000
GROSS WEIGHT, 20,000
SECOND ASSISTED TAKE OFF
FIRST ASSISTED TAKEOFF
× WITHOUT JET ASSISTANCE
O WITH JET ASSISTANCE

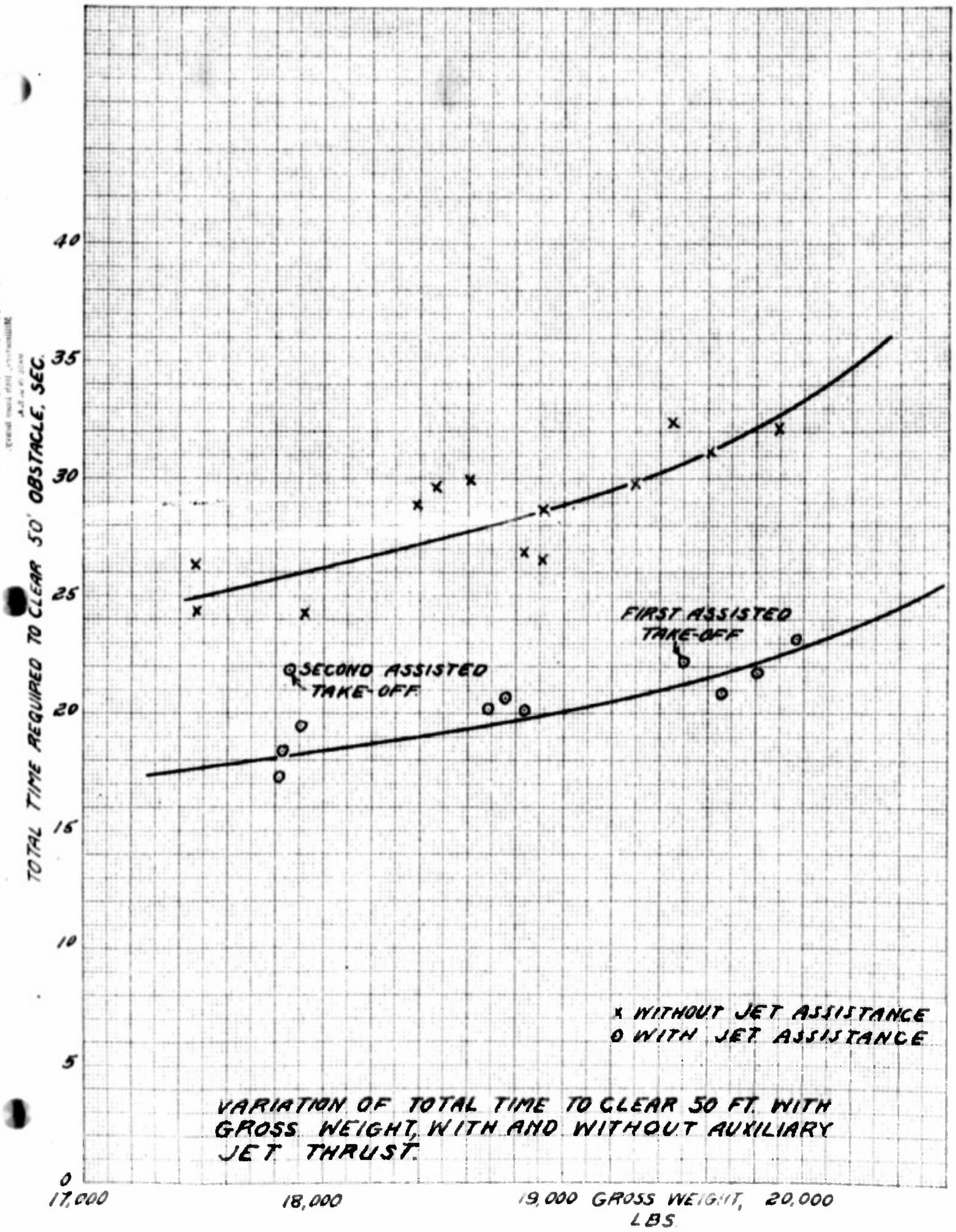


VARIATION OF TOTAL DISTANCE TO CLEAR 50 FT. WITH GROSS WEIGHT, WITH AND WITHOUT AUXILIARY JET THRUST



VARIATION OF TAKE-OFF TIME WITH GROSS WEIGHT, WITH AND WITHOUT AUXILIARY JET THRUST


VARIATION OF AIR BORNE TIME TO CLEAR 50 FT. WITH GROSS WEIGHT, WITH AND WITHOUT AUXILIARY JET THRUST.
AIR BORNE TIME REQUIRED TO CLEAR 50' OBSTACLE, SEC.
0
5
10
15
20
SECOND ASSISTED TAKE-OFF
FIRST ASSISTED TAKE-OFF
x WITHOUT JET ASSISTANCE
o WITH JET ASSISTANCE
17,000
18,000
19,000
GROSS WEIGHT, LBS.
20,000



VARIATION OF TOTAL TIME TO CLEAR 50 FT. WITH GROSS WEIGHT, WITH AND WITHOUT AUXILIARY JET THRUST.

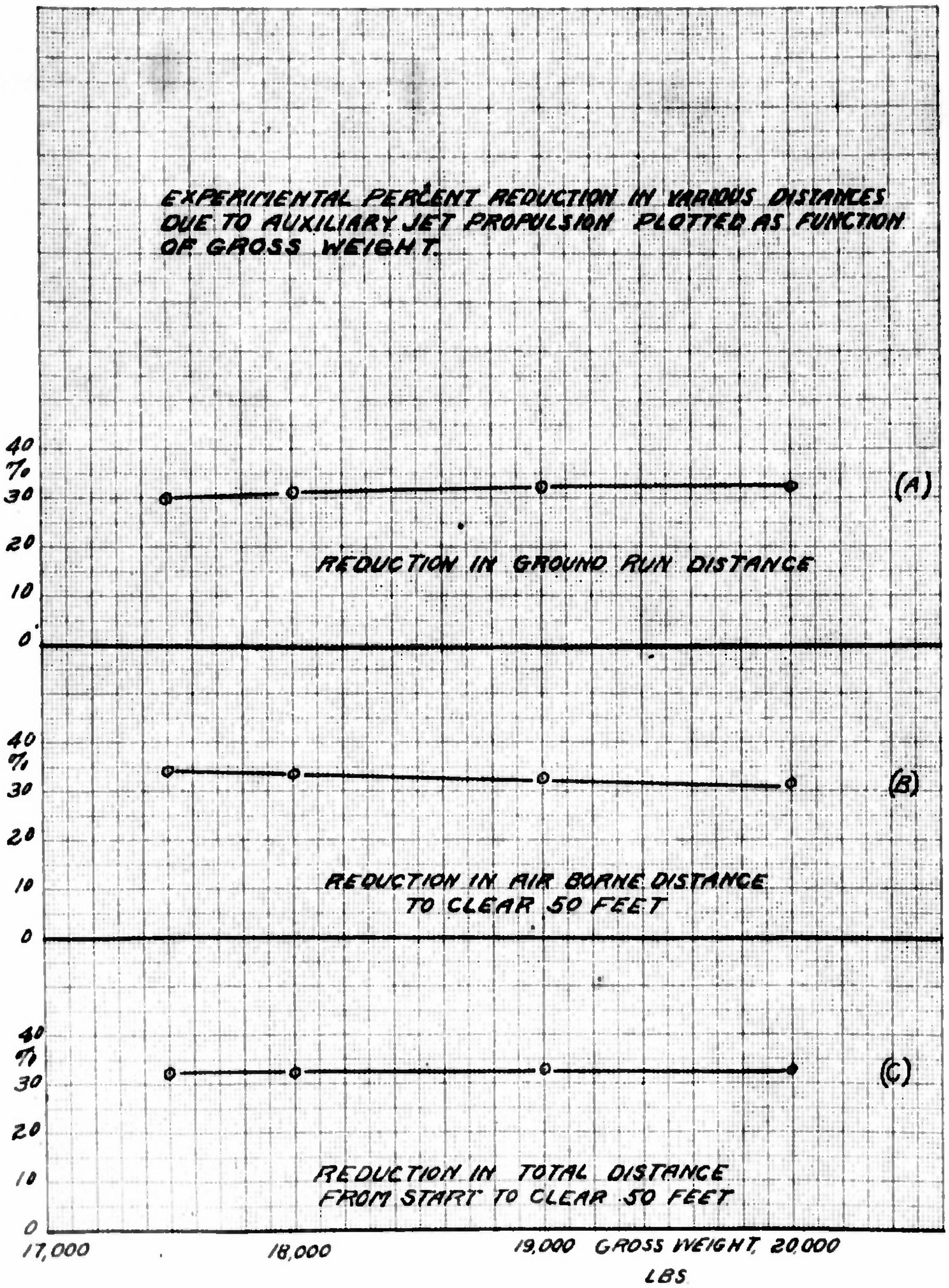

EXPERIMENTAL PERCENT REDUCTION IN VARIOUS DISTANCES DUE TO AUXILIARY JET PROPULSION PLOTTED AS FUNCTION OF GROSS WEIGHT.
40
%
30
20
10
0
(A)
REDUCTION IN GROUND RUN DISTANCE
(B)
REDUCTION IN AIR BORNE DISTANCE TO CLEAR 50 FEET
(C)
REDUCTION IN TOTAL DISTANCE FROM START TO CLEAR 50 FEET
17,000
18,000
19,000
GROSS WEIGHT
20,000
LBS

FIG. 43

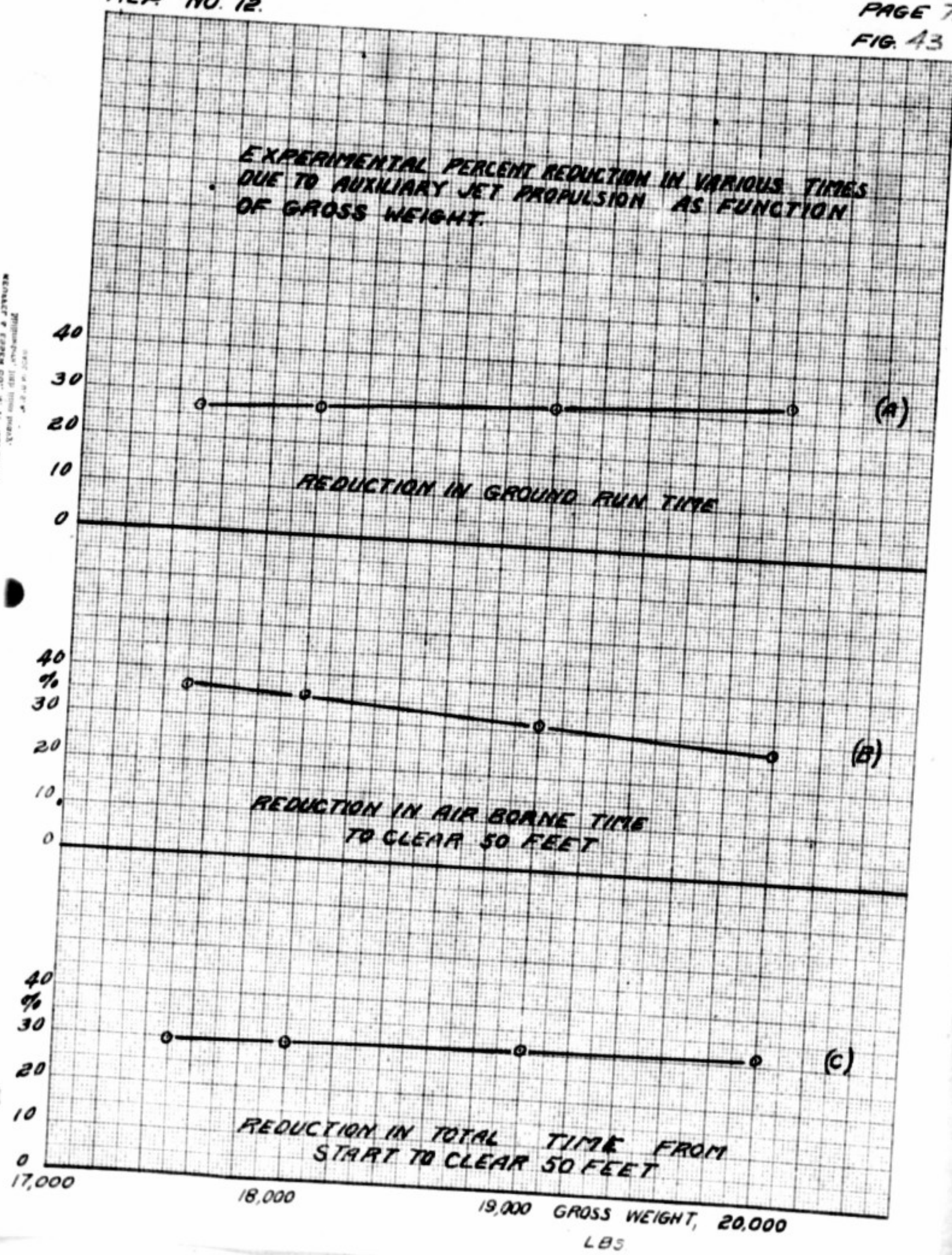
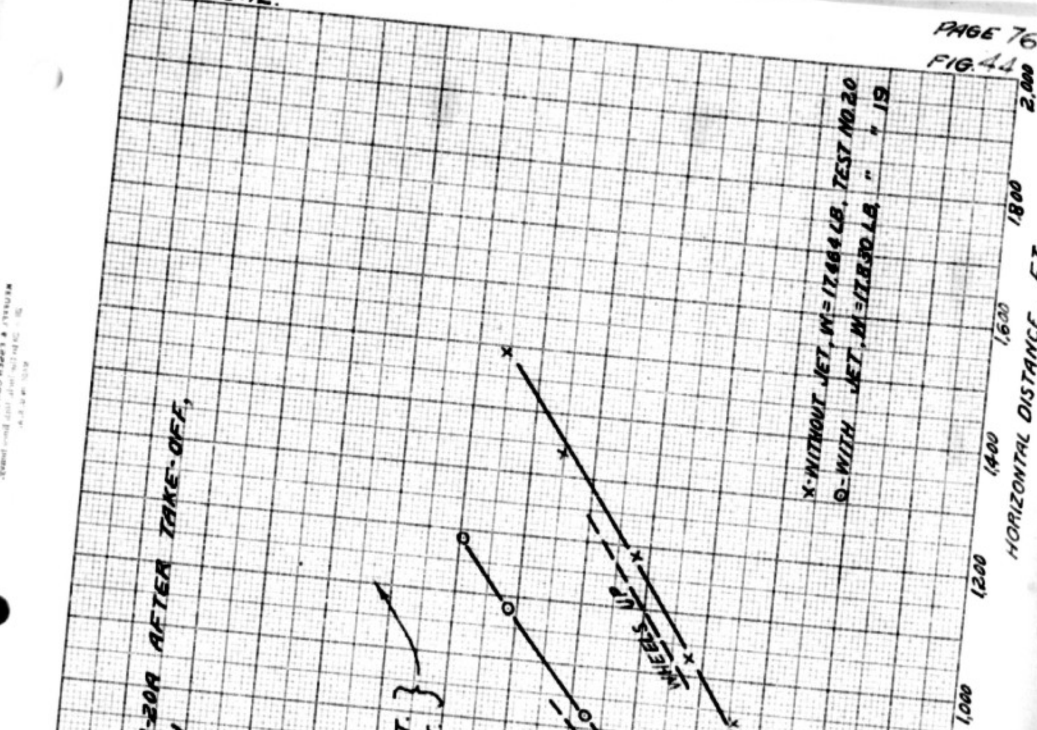
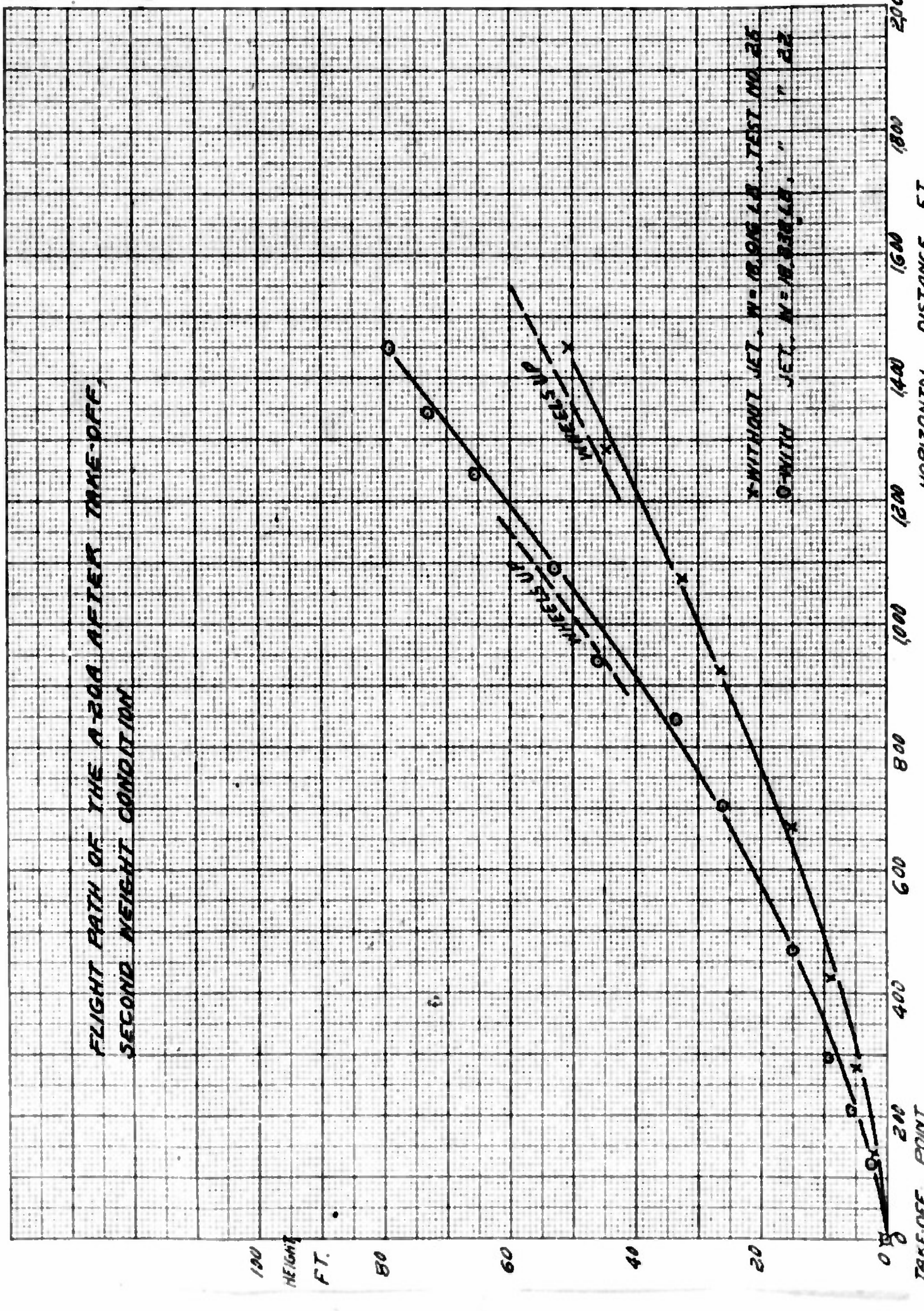
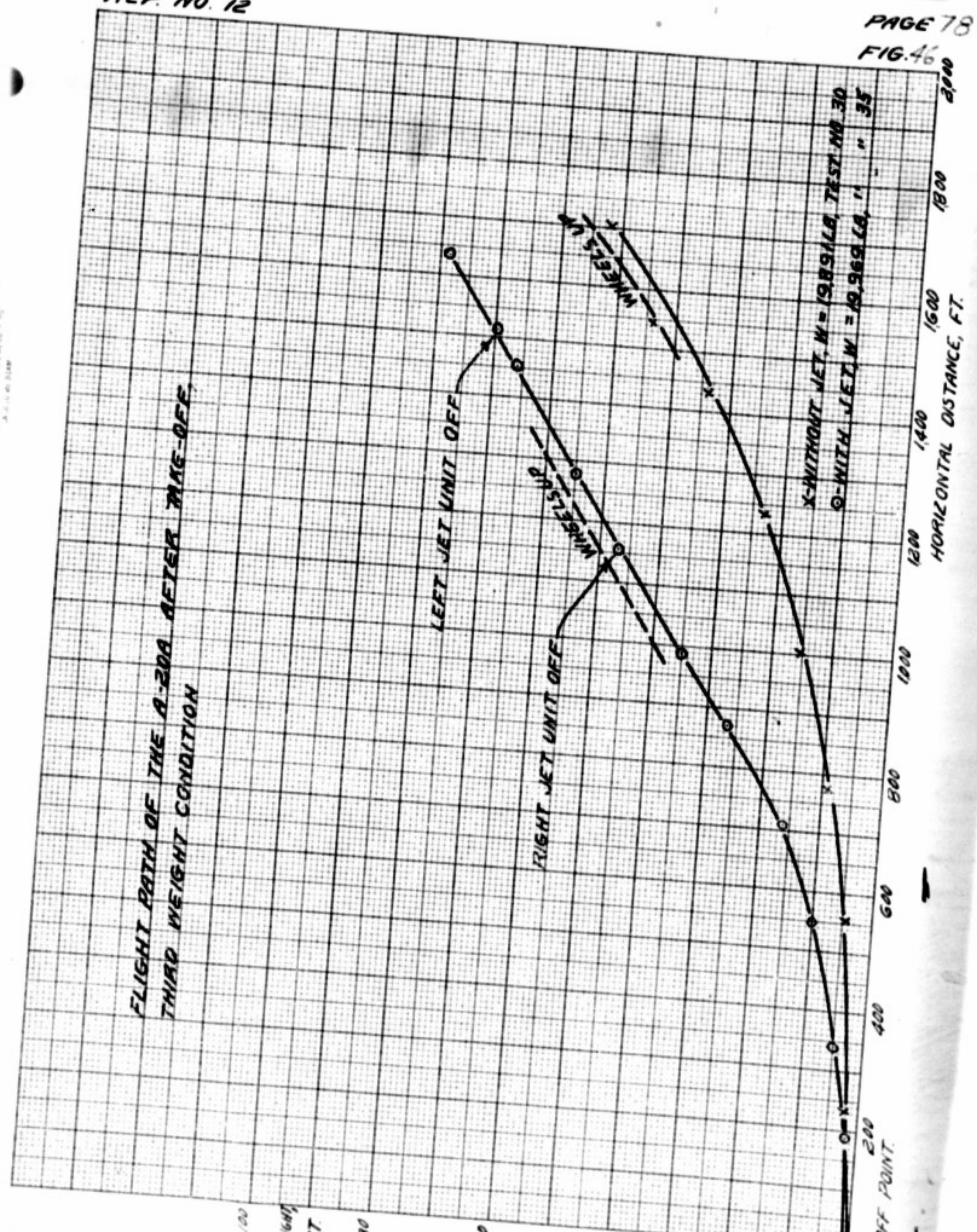

EXPERIMENTAL PERCENT REDUCTION IN VARIOUS TIMES DUE TO AUXILIARY JET PROPULSION AS FUNCTION OF GROSS WEIGHT.
40
30
20
10
0
(A)
REDUCTION IN GROUND RUN TIME
40
%
30
20
10
0
(B)
REDUCTION IN AIR BORNE TIME TO CLEAR 50 FEET
40
%
30
20
10
0
(C)
REDUCTION IN TOTAL TIME FROM START TO CLEAR 50 FEET
17,000
18,000
19,000
GROSS WEIGHT, LBS
20,000

FIG. 44

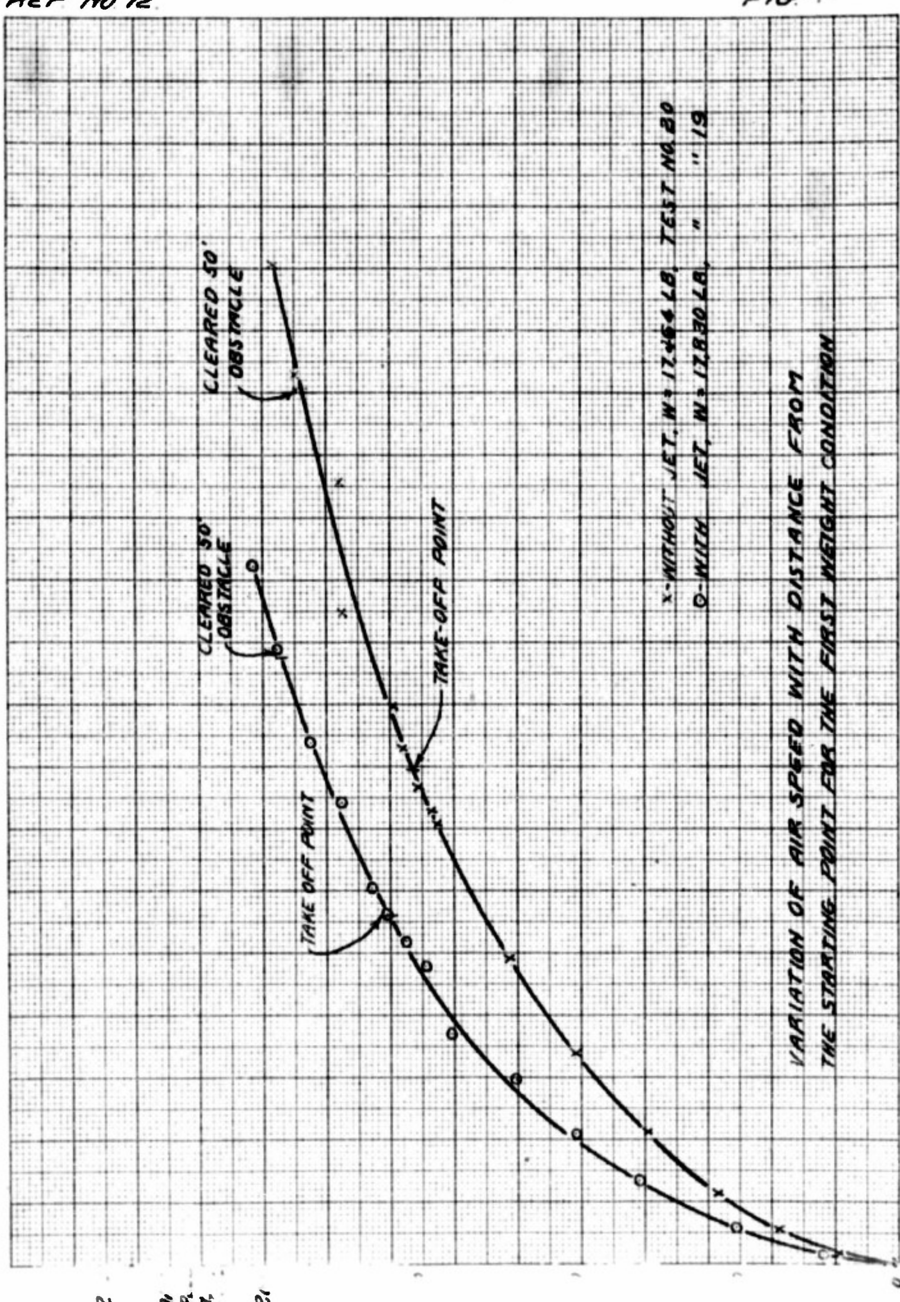

FLIGHT PATH OF THE A-20A AFTER TAKE-OFF,
FIRST WEIGHT CONDITION
RIGHT JET UNIT OFF AT 144.5 FT.
LEFT " " " 152.5 FT.
X-WITHOUT JET, W=17,464 LB. TEST NO.20
O-WITH JET, W=17,830 LB. " " 19
WHEELS UP
WHEELS UP
HEIGHT, FT.
100
80
60
40
20
10
0
TAKE-OFF POINT
200
400
600
800
1,000
1,200
1,400
1,600
1,800
2,000
HORIZONTAL DISTANCE, FT.


FLIGHT PATH OF THE A-20A AFTER TAKE-OFF,
SECOND WEIGHT CONDITION
x-WITHOUT JET
O-WITH JET
WHEELS UP
WHEELS UP
HEIGHT FT.
100
80
60
40
20
0
TAKE-OFF POINT
0
200
400
600
800
1000
1200
1400
1600
1800
2000
HORIZONTAL DISTANCE, FT.



FLIGHT PATH OF THE A-20A AFTER TAKE-OFF,
THIRD WEIGHT CONDITION

FIG. 47



VARIATION OF AIR SPEED WITH DISTANCE FROM THE STARTING POINT FOR THE FIRST WEIGHT CONDITION

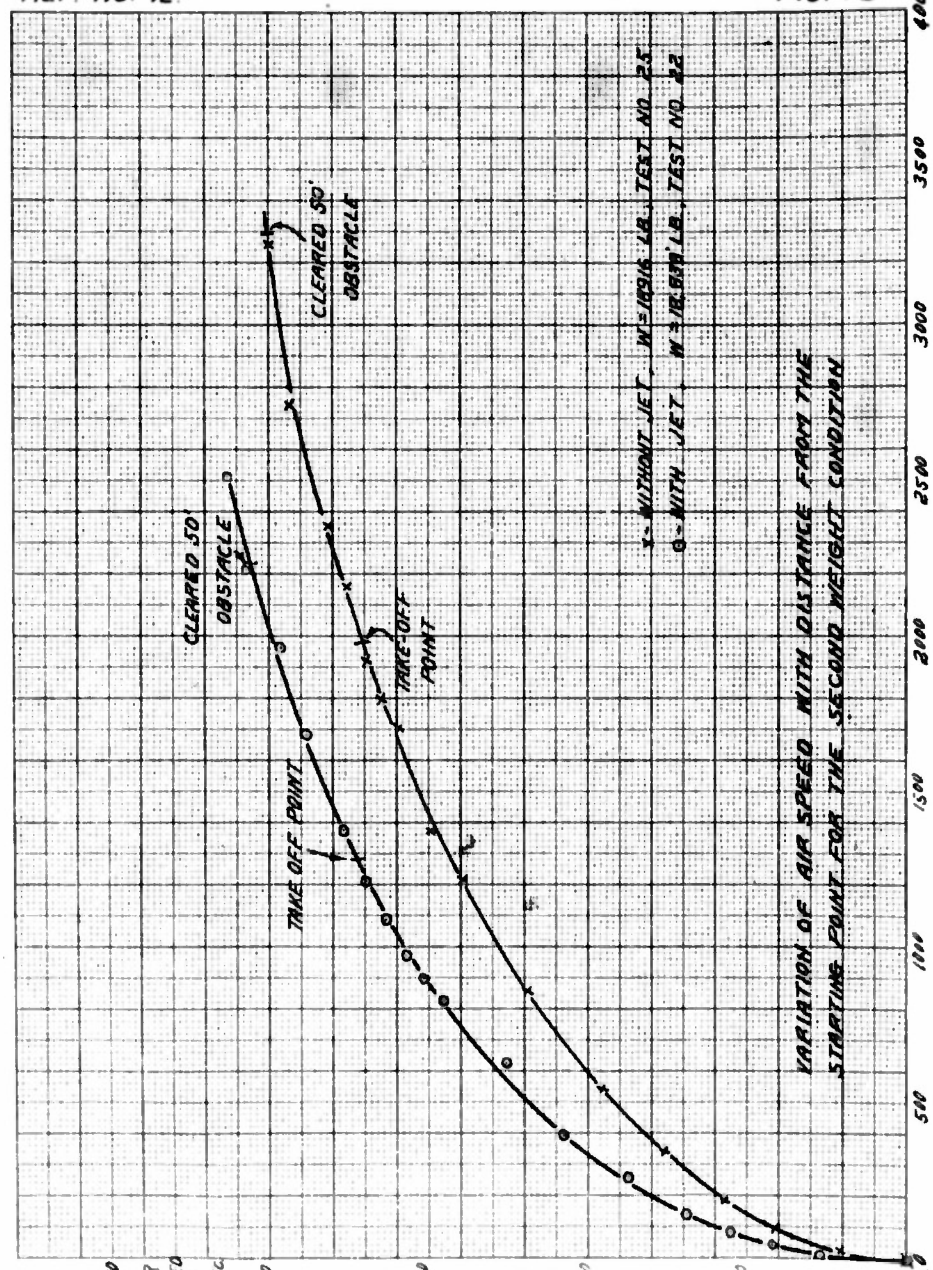
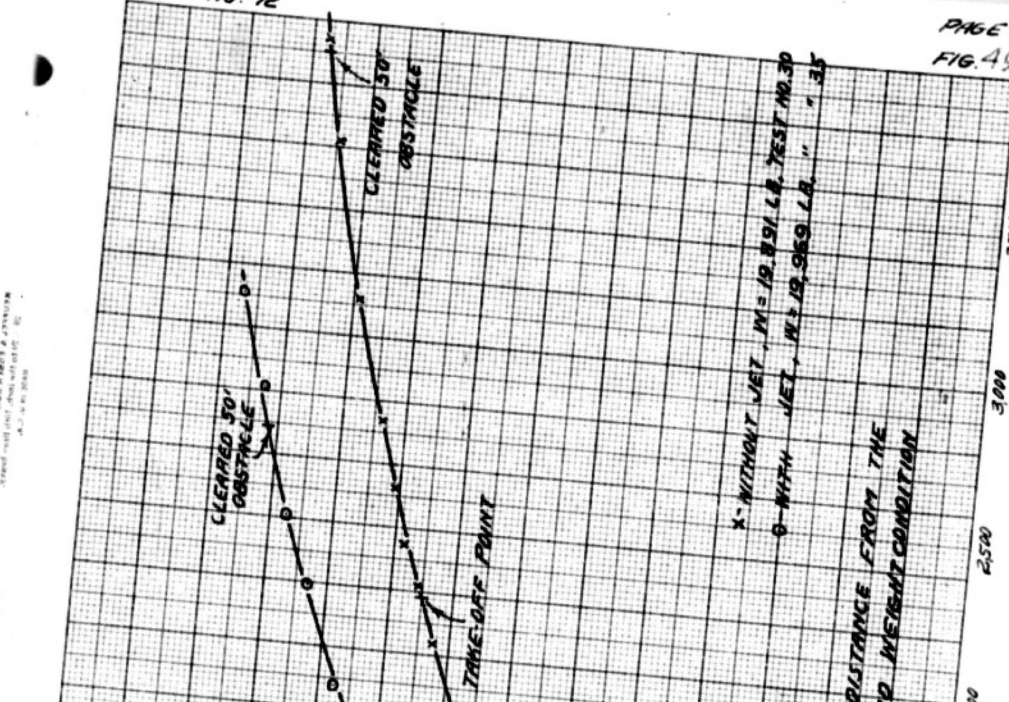

CLEARED 50' OBSTACLE
CLEARED 50' OBSTACLE
TAKE-OFF POINT
TAKE OFF POINT
X - WITHOUT JET, W=18916 LB., TEST NO. 25
O - WITH JET, TEST NO. 22
VARIATION OF AIR SPEED WITH DISTANCE FROM THE STARTING POINT FOR THE SECOND WEIGHT CONDITION
DISTANCE FROM START, FT.
0
500
1000
1500
2000
2500
3000
3500
4000
50
100
150
200

FIG. 49



VARIATION OF AIR SPEED WITH DISTANCE FROM THE STARTING POINT FOR THE THIRD WEIGHT CONDITION

FIG. 50

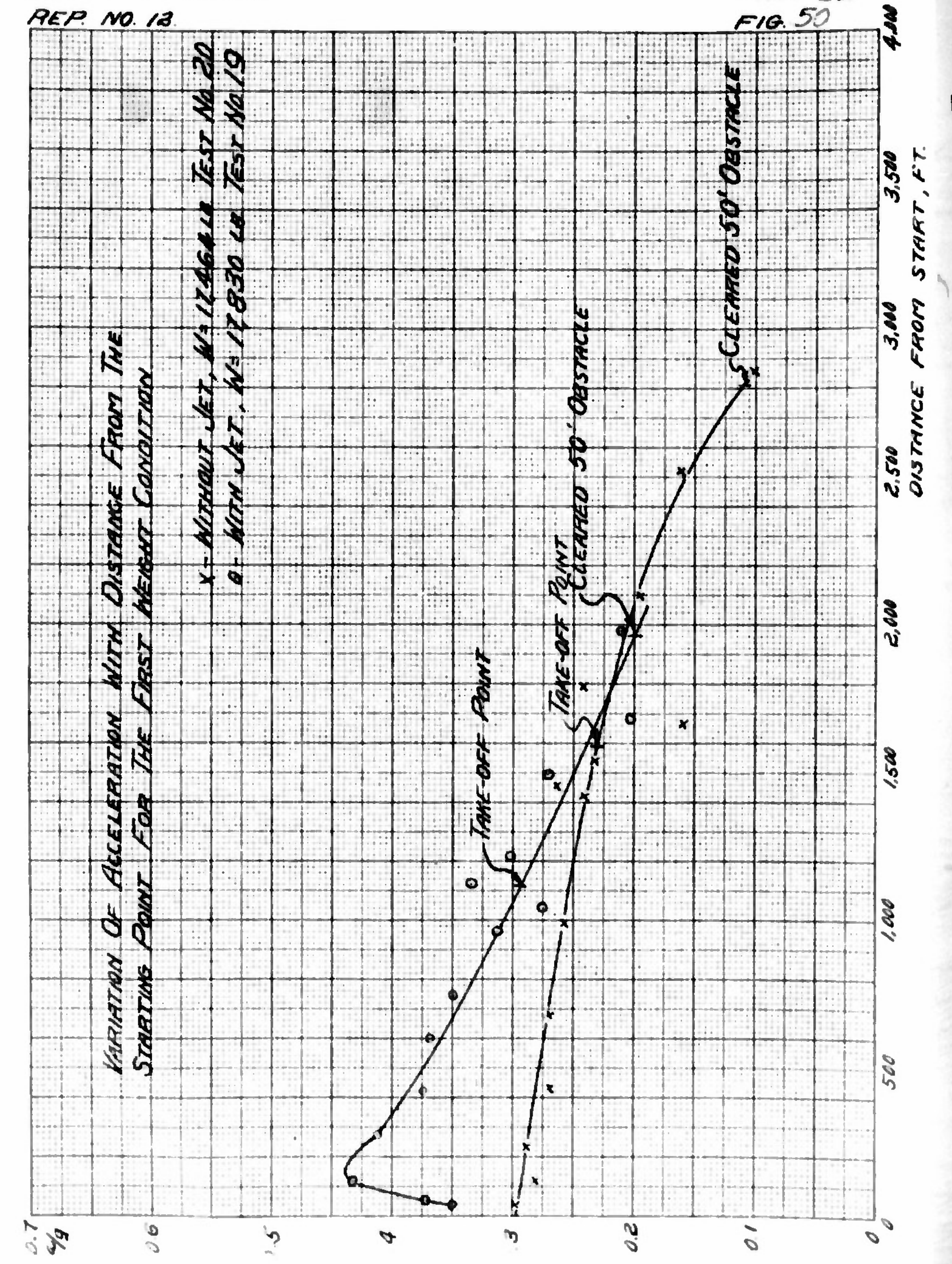

VARIATION OF ACCELERATION WITH DISTANCE FROM THE STARTING POINT FOR THE FIRST WEIGHT CONDITION
x - WITHOUT JET, W=17,464 LB TEST NO. 20
o - WITH JET, W=17,830 LB TEST NO. 19
TAKE-OFF POINT
TAKE-OFF POINT
CLEARED 50' OBSTACLE
CLEARED 50' OBSTACLE
a/g
0.7
.6
.5
.4
.3
0.2
0.1
0
0
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000
DISTANCE FROM START, FT.

FIG. 51

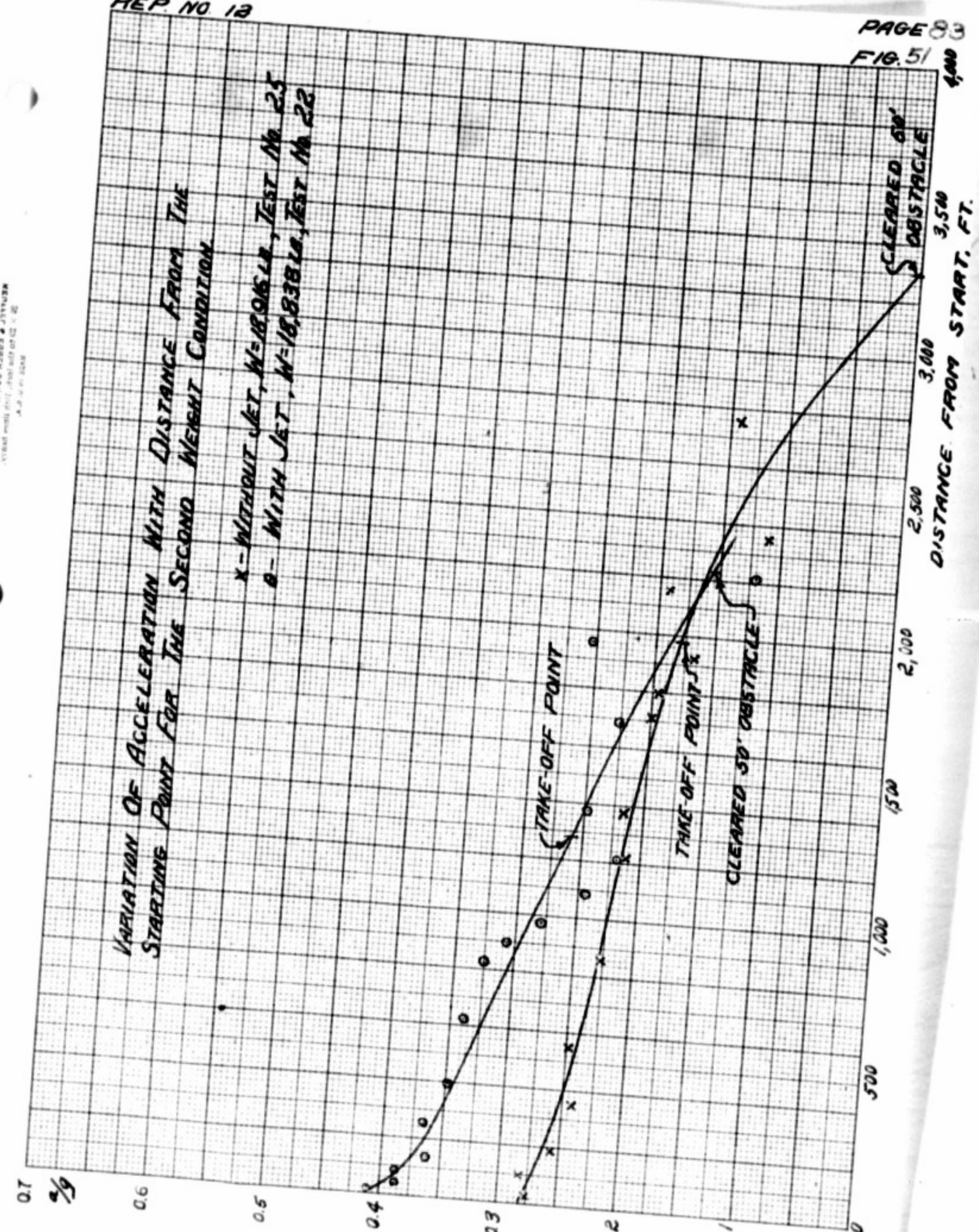
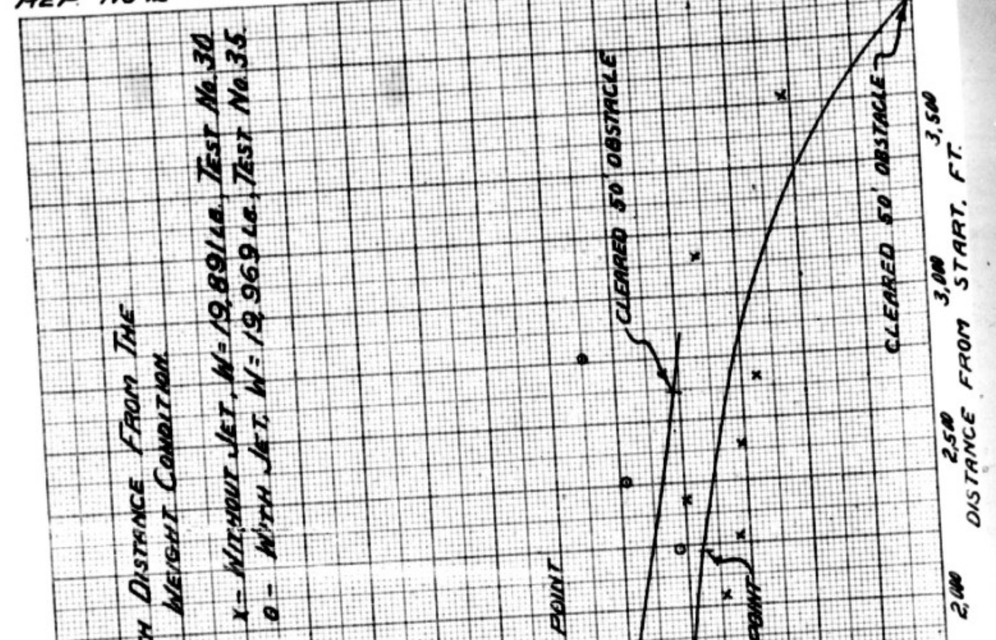
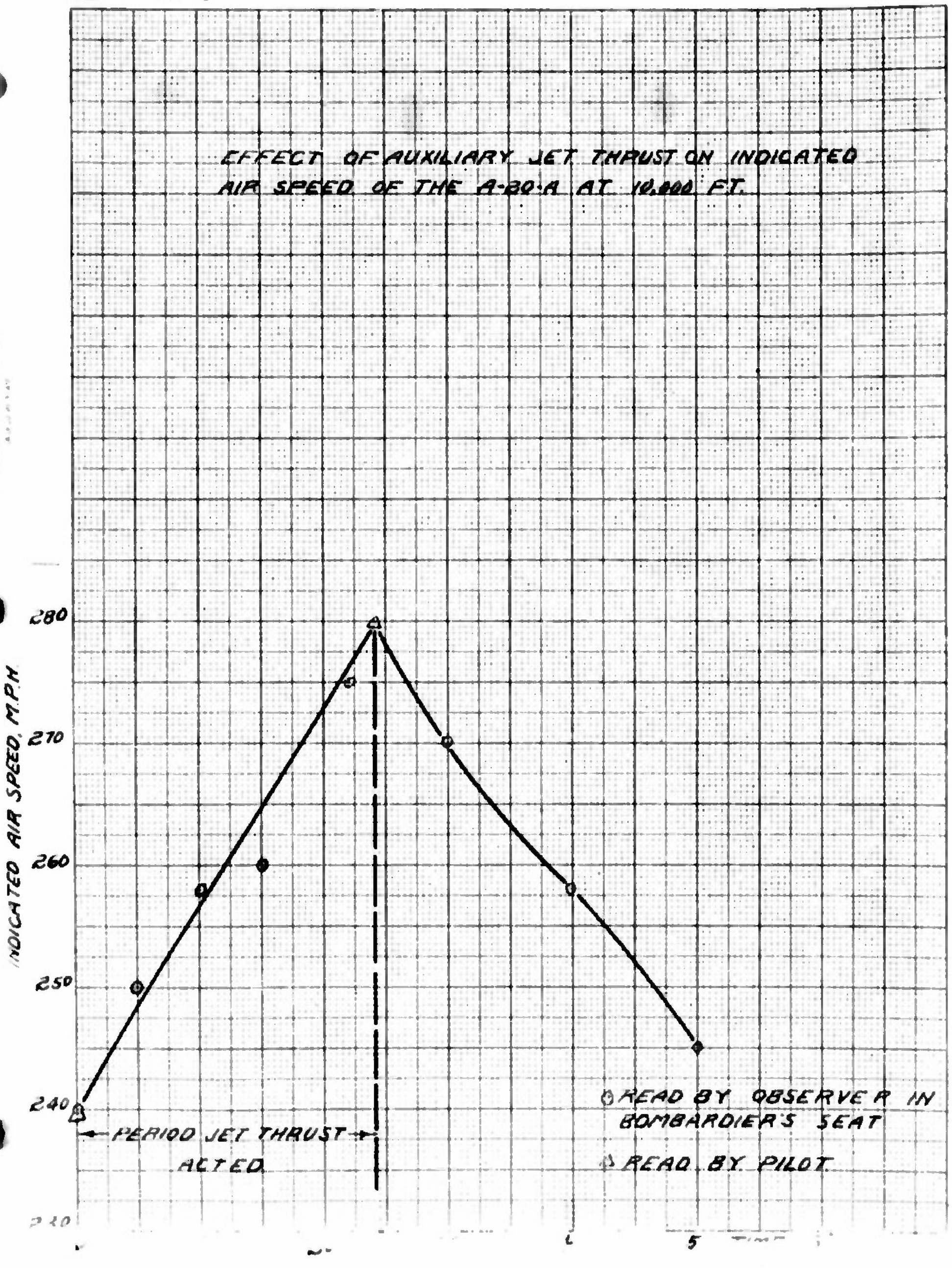
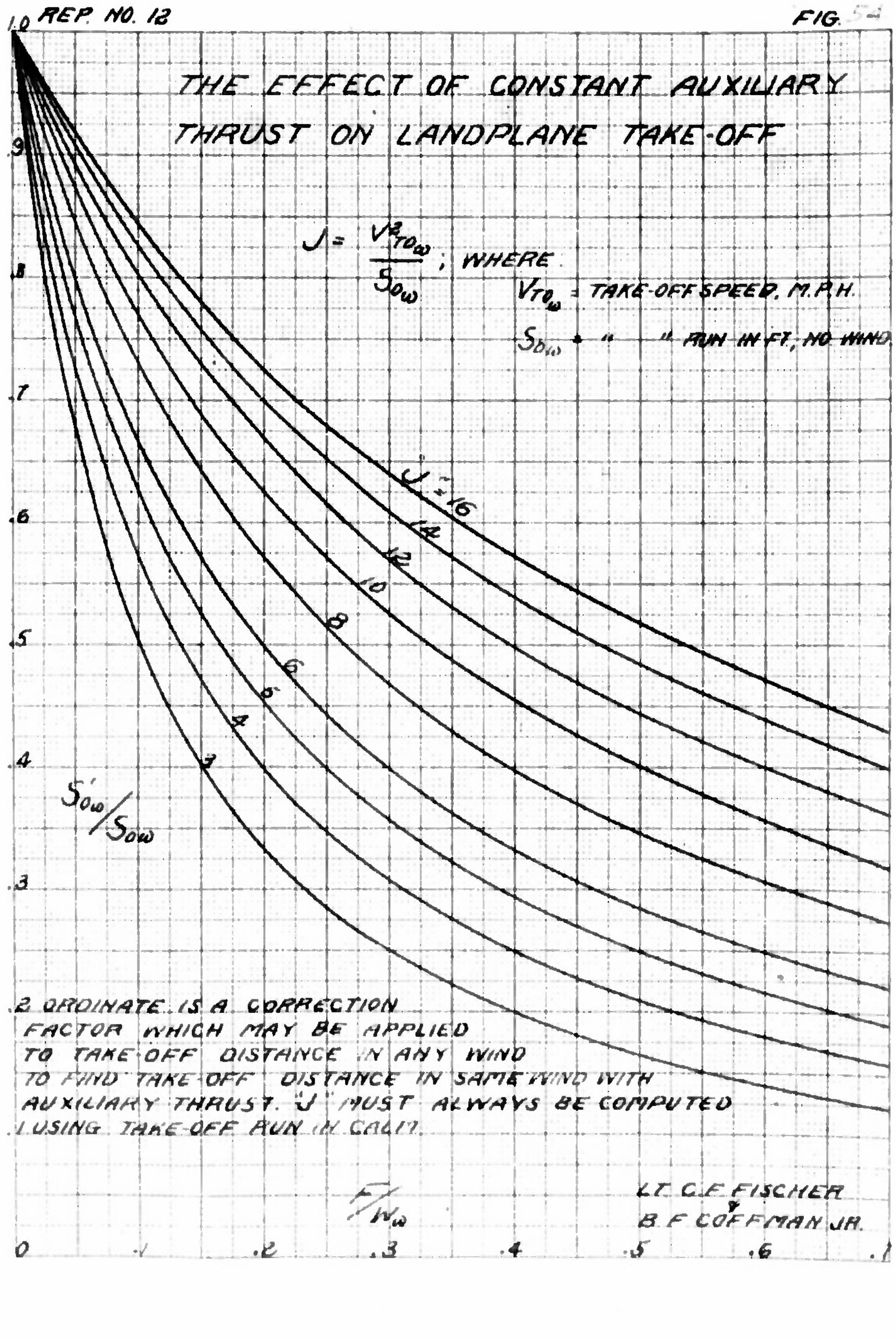
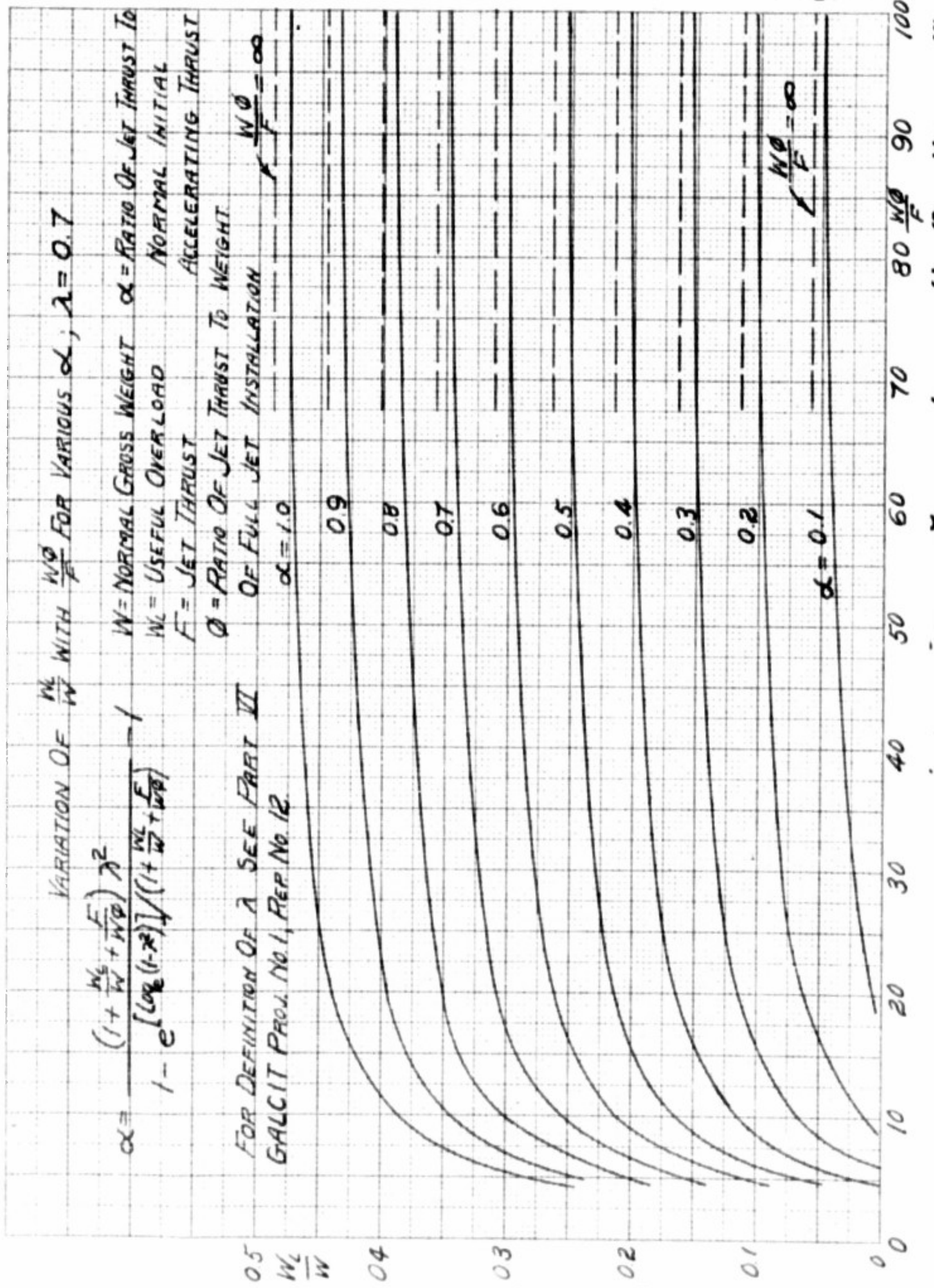

VARIATION OF ACCELERATION WITH DISTANCE FROM THE STARTING POINT FOR THE SECOND WEIGHT CONDITION
x - WITHOUT JET, W=18,016 LB., TEST NO. 25
⊙ - WITH JET, W=18,838 LB., TEST NO. 22
TAKE-OFF POINT
TAKE-OFF POINT
CLEARED 50' OBSTACLE
CLEARED 50' OBSTACLE
a/g
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000
DISTANCE FROM START, FT.

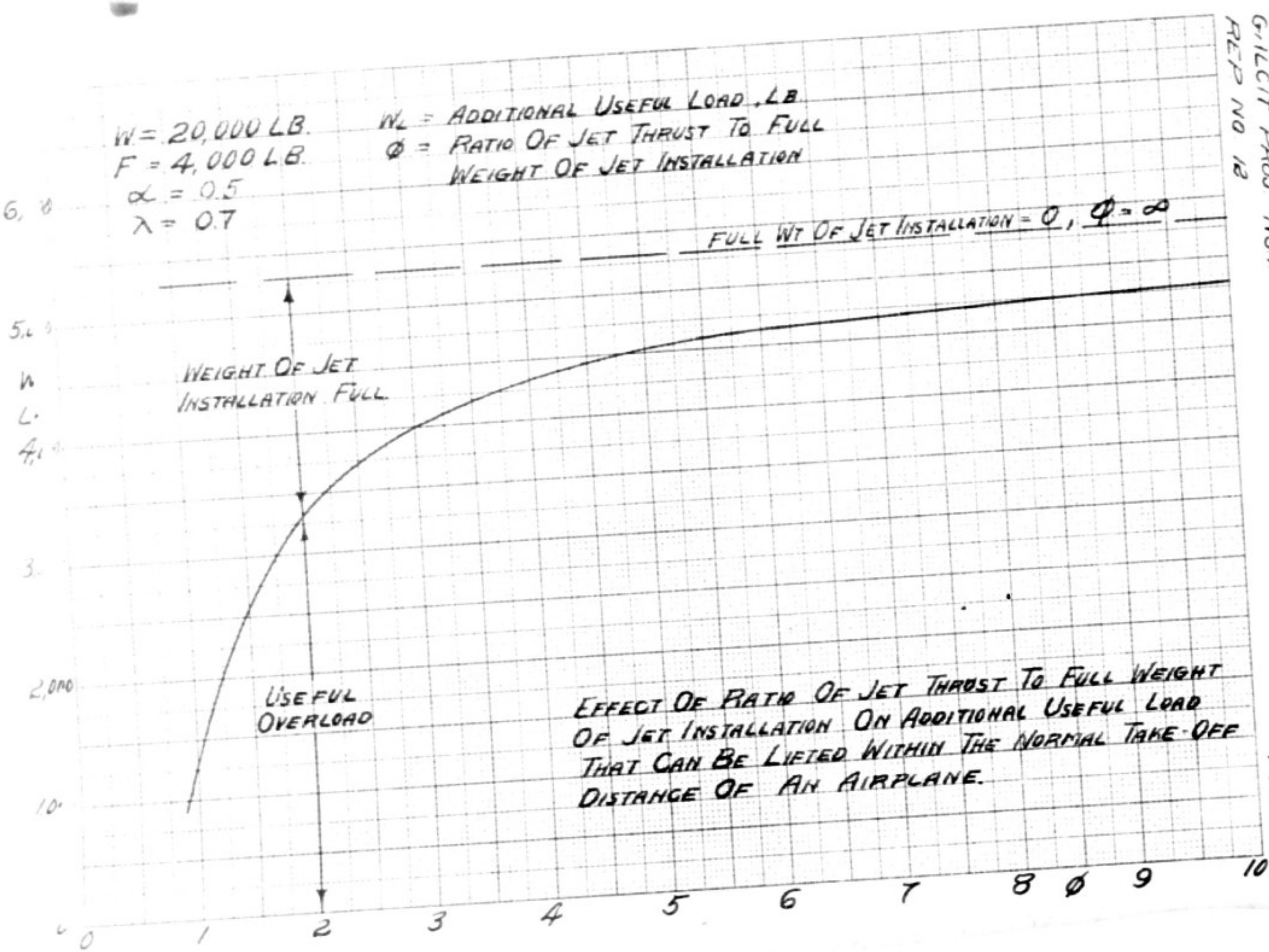
FIG. 52


VARIATION OF ACCELERATION WITH DISTANCE FROM THE STARTING POINT FOR THE THIRD WEIGHT CONDITION.
X - WITHOUT JET, W=19,891 LB. TEST NO. 30
O - WITH JET, W=19,969 LB., TEST NO. 35.
CLEARED 50' OBSTACLE
CLEARED 50' OBSTACLE
TAKE-OFF POINT
TAKE-OFF POINT
DISTANCE FROM START, FT.
0
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000
0.5
0.1
0


EFFECT OF AUXILIARY JET THRUST ON INDICATED AIR SPEED OF THE A-20-A AT 10,000 FT.
INDICATED AIR SPEED, M.P.H.
280
270
260
250
240
230
PERIOD JET THRUST ACTED
READ BY OBSERVER IN BOMBARDIER'S SEAT
READ BY PILOT
5


THE EFFECT OF CONSTANT AUXILIARY THRUST ON LANDPLANE TAKE-OFF
$J = \frac{V^2_{TO_\omega}}{S_{O_\omega}}$; WHERE
V_{TO_ω} = TAKE-OFF SPEED, M.P.H.
S_{O_ω} = " " RUN IN FT, NO WIND
J = 16
14
12
10
8
6
5
4
3
$S'_{O\omega}/S_{O\omega}$
ORDINATE IS A CORRECTION FACTOR WHICH MAY BE APPLIED TO TAKE-OFF DISTANCE IN ANY WIND TO FIND TAKE-OFF DISTANCE IN SAME WIND WITH AUXILIARY THRUST. "J" MUST ALWAYS BE COMPUTED USING TAKE-OFF RUN IN CALM.
F/W_ω
LT. C.E. FISCHER
& B.F. COFFMAN JR.
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
.1
.2
.3
.4
.5
.6
.7


VARIATION OF $\frac{W_L}{W}$ WITH $\frac{W\phi}{F}$ FOR VARIOUS α; $\lambda = 0.7$
$\alpha = \frac{\left(1+\frac{W_L}{W}+\frac{F}{W\phi}\right)\lambda^2}{1-e^{\left[\log_e(1-\lambda^2)\right]/\left(1+\frac{W_L}{W}+\frac{F}{W\phi}\right)}} - 1$
W = NORMAL GROSS WEIGHT
W_L = USEFUL OVERLOAD
F = JET THRUST
ϕ = RATIO OF JET THRUST TO WEIGHT OF FULL JET INSTALLATION
α = RATIO OF JET THRUST TO NORMAL INITIAL ACCELERATING THRUST
FOR DEFINITION OF λ SEE PART VI GALCIT PROJ. NO 1, REP NO. 12
$\alpha = 1.0$
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
$\alpha = 0.1$
$\frac{W\phi}{F} = \infty$
$\frac{W_L}{W}$
0.5
0.4
0.3
0.2
0.1
0
$\frac{W\phi}{F}$
0
10
20
30
40
50
60
70
80
90
100



EFFECT OF RATIO OF JET THRUST TO FULL WEIGHT OF JET INSTALLATION ON ADDITIONAL USEFUL LOAD THAT CAN BE LIFTED WITHIN THE NORMAL TAKE-OFF DISTANCE OF AN AIRPLANE.

DEPARTMENT OF COMMERCE
CIVIL AERONAUTICS ADMINISTRATION
WASHINGTON, D. C.

MILITARY PROJECTS SERIES
ARMY AIR FORCES REPORT NO. 3

SPACE TIME RECORDS OF TAKE-OFF PERFORMANCE OF A-20A AIRPLANE WITH AND WITHOUT ASSISTANCE FROM JET PROPULSION

MAY 21, 1942

FLIGHT ENGINEERING & FACTORY INSPECTION DIVISION

TABLE OF CONTENTS

REFERENCES

(1) Military Projects Series Army Air Forces Report Number 2 - "Installation of Equipment for Recording Airplane Take-Off and Landing Characteristics at Muroc Bombing and Gunnery Range, Rogers Dry Lake, California."

(2) Flight Engineering Report Number 4- "C. A. A. Equipment for Recording Airplane Take-Off and Landing Characteristics."

PART I

PURPOSE

The purpose of this report is to present the results (space time records) of the analysis of the film exposed, during 25 take-offs of the A-20-A airplane at Muroc Dry Lake, in the C.A.A. cameras for recording airplane take-off and landing performance, and to furnish the observed ground data recorded by the ground crew operating the camera equipment.

In addition to the space time records the actual ground speeds are also calculated for all portions of the runs analyzed.

LOCATION AND DATE OF TESTS

The test flights were made on the 12,000 foot test course at Muroc Dry Lake, U. S. Air Forces Bombing and Gunnery Range, Muroc, California (described in "Military Projects Series Army Air Forces Report No. 2") from April 15 to April 24, 1942. The film analysis was accomplished with the aid of the projector set-up located at the Santa Monica office of the Civil Aeronautics Administration during the period from April 27, 1942 to May 4, 1942. The calculations were made at the Santa Monica office and at the Arroyo Seco Rocket Camp of the California Institute of Technology, Pasadena, California from May 5 to May 8, 1942.

EQUIPMENT

The distances, times, and airplane speeds listed in the tabulation, "Summary of Results", Page 4, were obtained photographically, using the Civil Aeronautics Administration motion picture camera equipment, projector set-up, and field layout described in C. A. A.

Flight Engineering Report No. 4, "C.A.A. Equipment for Recording Airplane Take-Off and Landing Characteristics." The procedure therein described was amplified to obtain two film records of each run by erecting a second camera opposite marker 49 in addition to the one opposite marker 50. Of the duplicate films thus obtained, only a single set was analyzed.

For wind velocities, a windmill-type anemometer was erected on a tripod with weather-vane head. Its location was 7 feet above the ground and at the number 50 marker, on the line of markers.

PERSONNEL PARTICIPATING IN TESTS

Major Paul Dane	Airplane Pilot	Wright Field, Dayton.
Mr. Joseph Matulaitis) Corporal Poll) Private Taylor)	Anemometer Observers.	C.A.A., D.C. Muroc Lake Muroc Lake
Mr. Elisha Fales) Mr. Norman Rubin)	Camera Operators.	C.A.A., D.C.
Dr. Frank Malina) Mr. E. G. Crofut) Mr. Richard Canright)	Take-Off Spotters.	Cal. Inst. of Technology Pasadena, Cal.
Mr. Robert Turbeck) Mr. Art Richardson)	Signalmen at Airplane.	Cal. Inst. of Technology.
Mr. Beverly Forman) Mr. Walter Powell)	Operators of Rocket Jets in Airplane.	Cal. Inst. of Technology.
Mr. Richard Canright) Mrs. Richard Canright)	Computers	Cal. Inst. of Technology
Mrs. G. Keithley) Miss Sallie Barnett)	Secretaries	C.A.A., Santa Monica, Cal.
Mr. Elisha Fales) Mr. Norman Rubin)	Analysis of Film & Prep. of Report	C.A.A., D.C.

RESULTS

The results obtained from the film analysis and the ground crew notes will be found summarized in tabular form on Page 4-A. This table includes, for each run, the observed ground speeds, distances, times of run, wind speed and direction, outside air temperature, pressure altitude, and airplane weight.

Plots of ground run and distance to clear a fifty foot obstacle against airplane weight may be found on Pages 5-A and 6-A respectively.

The data of Run 17 have not been entered on the graph, as the pilot reported after this run that the throttle was incorrectly set.

It should be noted that the summary table on Page 4-A and the data plotted on Pages 5-A and 6-A do not include the distances corrected for such variables as wind, outside air temperature and pressure altitude and that in all cases only observed data are shown in this report.

Typed copies of the film analysis work sheets for all 25 runs are included on Pages 11-A through 59-A. Each run is designated by a "Run" number which agrees with the run number used in the summary table.

It will be noted that all runs have been analyzed throughout in order to permit obtaining complete acceleration data. Although no plot is made of the latter results in this report, this basic information is furnished in order to permit further study of the accelerations obtained during the take-off run with and without assistance from the jet propulsion.

SUMMARY OF RESULTS AND OBSERVED DATA

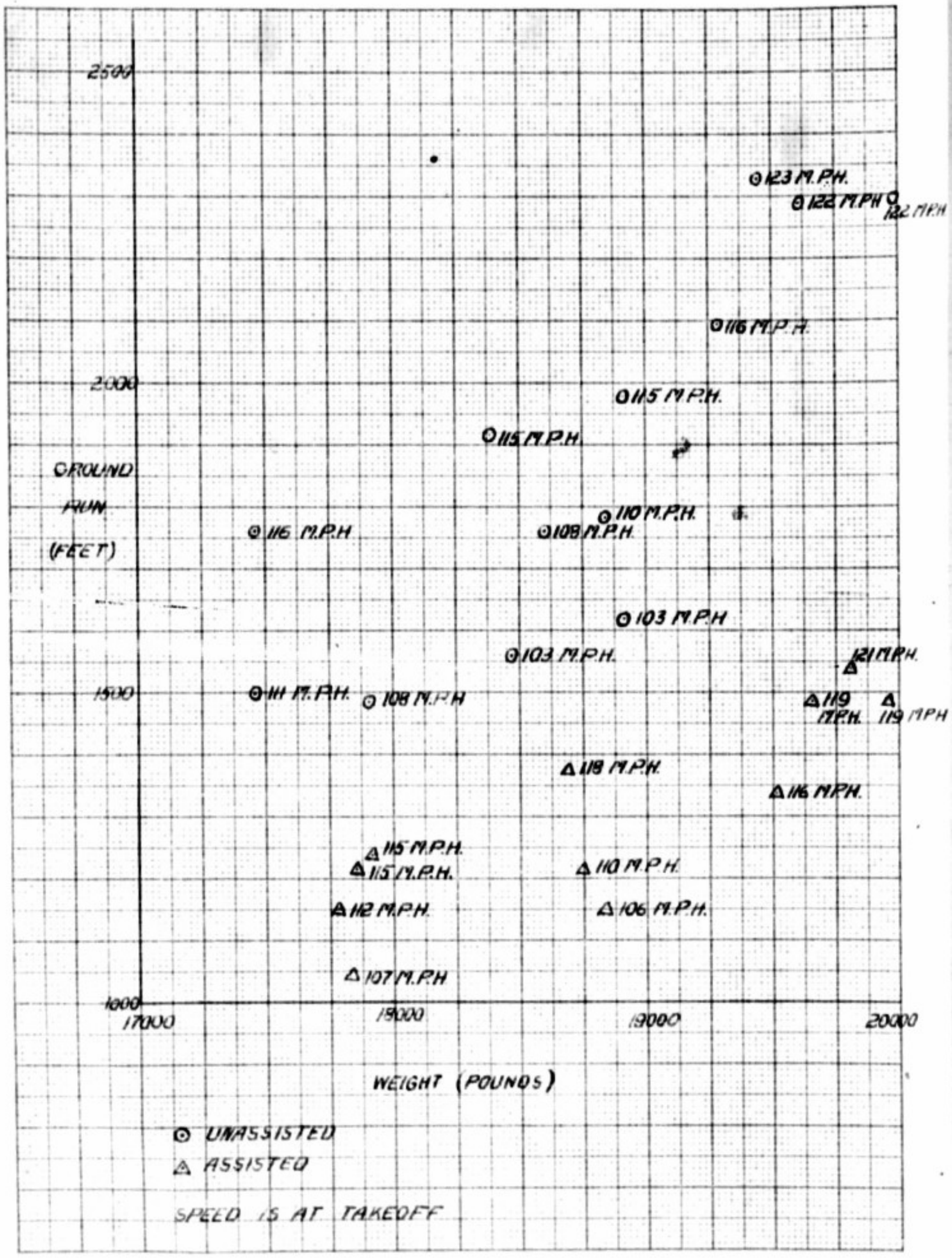
General Information							Ground Run Data (observed)			Air Run Data (observed)				Total Run** (observed)	
Run No.	Assisted or Unassisted	Airplane Weight	Pressure Altitude	Outside Air Temp.	Wind Velocity	Wind Angle to Direction of Take-off*	Time of Ground Run	Ground Speed at Take-off	Distance to Take-off Point	Time to Clear 50'	Airplane Ground Speed at 50' Ht.	Dist. to Clear 50' Ht.	Time	Distance
		Lbs.	Ft.	°F.	M.P.H.	Degrees	Secs.	M.P.H.	Ft.	Sec.	M.P.H.	Ft.	Sec.	Ft.
10	A	19504	2500	74	6.3	10	14.96	116	1332	7.21	151	1453	22.17	2785
11	U	17908	2060	62	1.1	110	18.30	108	1492	6.01	124	1038	24.31	2530
12	A	17860	"	65	3.5	120	15.07	115	1212	6.82	151	1332	21.89	2544
13	U	17464	"	66	.6	"	17.58	111	1499	6.82	128	1238	24.40	2737
17	A	17908	2200	65	7.2	50	15.99	103	1231	7.29	135	1304	24.28	2535
18	A	"	2340	51	3.1	110	15.08	115	1236	4.40	140	831	19.48	2067
19	A	17630	"	58	5.0	160	13.93	112	1153	4.47	134	813	18.40	1966
20	U	17464	"	59	6.2	100	18.93	116	1780	6.40	136	1170	26.33	2930
21	U	18916	2390	67	9.3	30	19.91	103	1618	6.66	122	1099	26.57	2717
22	A	18838	"	68	10.2	50	14.31	106	1150	5.74	133	1013	20.05	2163
23	U	18472	"	69	8.0	70	18.93	103	1553	10.74	128	ii 834	29.67	3367
24	A	18682	"	70	9.1	100	15.63	118	1376	4.56	137	854	20.19	2230
25	U	18916	2370	55	6.7	90	21.67	116	1977	7.04	136	1314	28.71	3291
26	U	18838	"	55	3.8	75	20.33	110	1780	6.56	129	1146	26.89	2928
27	A	18760	"	59	5.0	15	14.69	110	1218	5.05	136	933	19.74	2151
28	U	18394	"	59	3.9	50	21.09	115	1918	7.80	136	1462	28.89	3380
29	U	18604	"	70	11.5	50	21.58	108	1761	8.32	128	1472	29.90	3233
30	U	19981 i	2340	65	7.8	150	23.77	122	2298	8.38	149	1673	32.15	3971
31	A	19810	"	67	5.9	70	16.72	121	1537	4.95	145	973	21.67	2510
32	U	19447	"	66	7.7	130	23.91	123	2325	8.44	150	1590	32.35	3915
33	A	19657	2360	70	6.6	160	15.65	119	1485	5.21	141	1015	20.88	2500
34	U	19291	"	71	3.4	0	22.95	116	2093	6.84	134	1262	29.79	3355
35	A	19969	"	67	5.0	80	17.08	119	1488	6.10	151	1197	23.18	2685
36	U	19603	"	66	4.3	170	24.25	122	2288	6.97	165	1403	31.22	3691
37	A	17830	2200	67	2.9	20	13.06	107	1048	4.21	127	729	17.27	1777

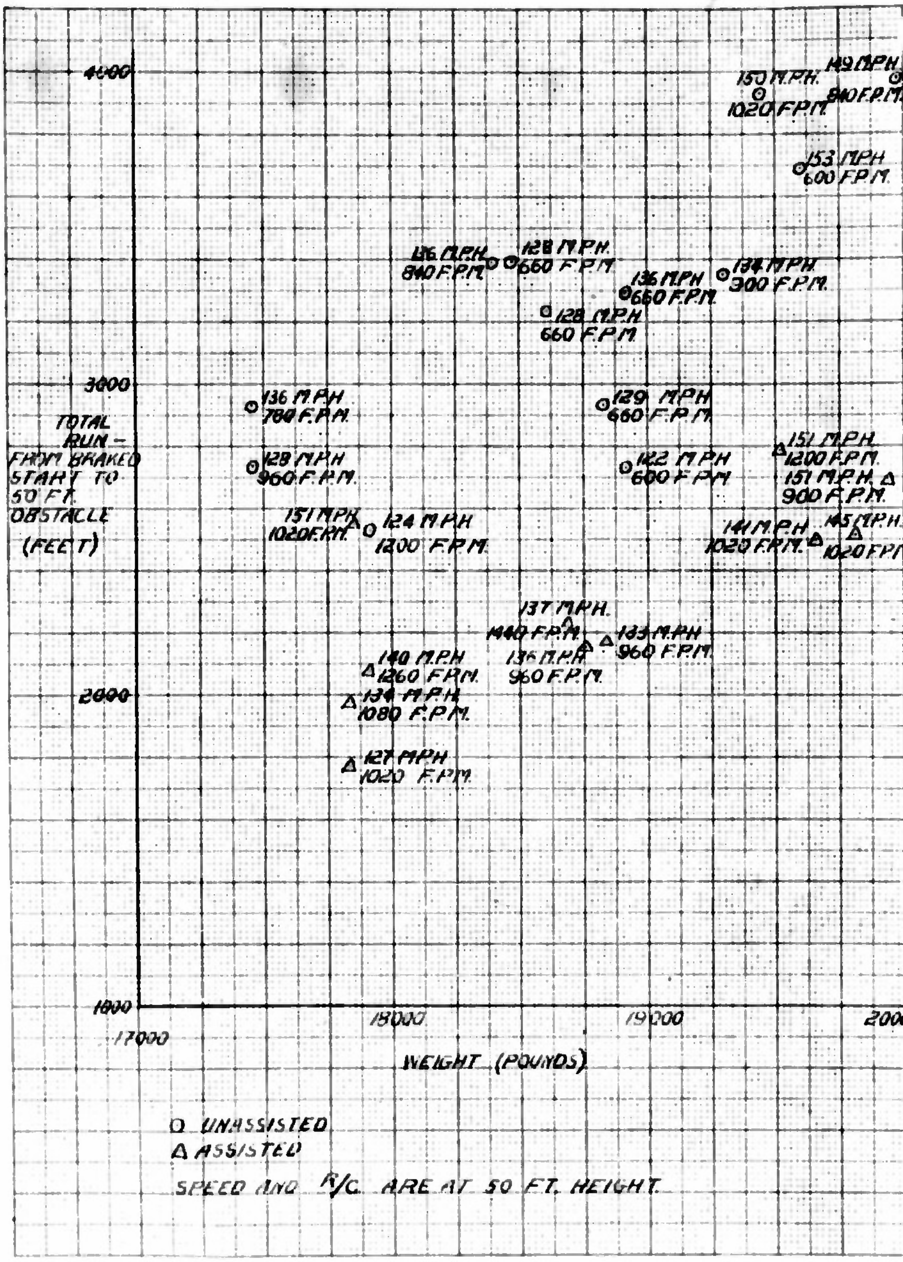
* 0° to 90° indicates headwind. 90° to 180° indicates tail wind.

** Entire run from braked start to clearance of 50-ft. obstacle.

i Correct weight, 19,891 (F. J. M.)

ii Corect distance, 1,334 (F. J. M.)


2500
2000
1500
1000
GROUND RUN (FEET)
17000
18000
19000
20000
WEIGHT (POUNDS)
123 M.P.H.
122 M.P.H.
122 M.P.H.
116 M.P.H.
115 M.P.H.
115 M.P.H.
110 M.P.H.
108 M.P.H.
116 M.P.H.
103 M.P.H.
103 M.P.H.
121 M.P.H.
111 M.P.H.
108 M.P.H.
119 M.P.H.
119 M.P.H.
118 M.P.H.
116 M.P.H.
115 M.P.H.
115 M.P.H.
110 M.P.H.
112 M.P.H.
106 M.P.H.
107 M.P.H.
UNASSISTED
ASSISTED
SPEED IS AT TAKEOFF


4000
3000
2000
1000
TOTAL RUN — FROM BRAKED START TO 50 FT. OBSTACLE (FEET)
17000
18000
19000
20000
WEIGHT (POUNDS)
150 M.P.H. 1020 F.P.M.
149 M.P.H. 840 F.P.M.
153 M.P.H. 600 F.P.M.
136 M.P.H. 840 F.P.M.
128 M.P.H. 660 F.P.M.
136 M.P.H. 660 F.P.M.
134 M.P.H. 300 F.P.M.
128 M.P.H. 660 F.P.M.
136 M.P.H. 780 F.P.M.
129 M.P.H. 660 F.P.M.
128 M.P.H. 960 F.P.M.
142 M.P.H. 600 F.P.M.
151 M.P.H. 1200 F.P.M.
151 M.P.H. 900 F.P.M.
151 M.P.H. 1020 F.P.M.
124 M.P.H. 1200 F.P.M.
141 M.P.H. 1020 F.P.M.
145 M.P.H. 1020 F.P.M.
137 M.P.H. 1440 F.P.M.
136 M.P.H. 960 F.P.M.
133 M.P.H. 960 F.P.M.
140 M.P.H. 1260 F.P.M.
134 M.P.H. 1080 F.P.M.
127 M.P.H. 1020 F.P.M.
O UNASSISTED
Δ ASSISTED
SPEED AND R/C ARE AT 50 FT. HEIGHT.

PART II

REMARKS REGARDING DETAILS OF FILM ANALYSIS AND CALCULATIONS

General

For all the film analyses the airplane reference point for horizontal distances was the Rudder Trailing Edge, taken at the level of the top of the fuselage, and for vertical distances, the top of the tail. Since the "Flag Take-Off" (take-off point noted by ground crew) position referred to the wheels, the film reading of the "Flag Take-Off" as read and as typed may be corrected to the rudder trailing edge by adding 27 feet in the case of Runs 18 to 37 (East to West Runs) and subtracting 27 feet in the case of Runs 10 to 17 (West to East Runs). (Markers are numbered consecutively with the magnitude of the numbers increasing from West to East.)

All horizontal distances taken from the "left camera", which was set 100 feet away from the conventional position (Runs 30 to 34), read 100 feet higher than the figures appearing on the field markers. However, the distance values of any one run are consistent among themselves. (This 100 foot difference is due to the fact that the markers are so located that the 50 marker, or center of the course, is opposite the right camera station.)

In certain runs (20, 26, 28) the data did not record the exact start of the airplane, due to invisibility of the starter's signal. In these cases, the starting station and time were satisfactorily extrapolated backwards by fitting a parabola to the time-distance curve, and solving for the vertex of the parabola.

On certain films the airplane failed to reach 50-foot height within the extablished marker course. For films in which this gap was small, extrapolation of the climb curve was used. For the larger gaps (Runs 23, 30, 32, 36) the following expedient was adopted:

> An extension scale board was calculated and laid out extending the scale board stations from Marker 27, the normal limit, to Marker 20, and with the film in the projector, landmarks, mirrage reflections, and terrain elevations were then correlated with the last marker. The elevations and horizontal distances thus determined had an accuracy better than 5 and 10 feet respectively.

The weights tabulated in the summary table were based on an original weighing of the airplane at Wright Field before the installation in California of the Rocket Motors. Subsequent weights were estimated by the California Institute of Technology Rocket group, by allowing for additione of structure, equipment, fuel, and personnel carried by the airplane in each test.

The apparent airplane dimensions analyzed in the films for taxiing attitude (except as noted), at Marker #50 were:

Wheel Axle to Tail Reference Point,	horizontal	= 27	feet
Bottom of Wheel " " " ,	vertical..........	= 18	feet
C. G. to " " " " ,	horizontal.......	= 31	feet
C. G. " " " " ,	vertical..........	= 9.5	feet
C. G. " Bottom of Wheel " ,	vertical..........	= 8.5	feet
C. G. " Tail Reference Point,	vertical (flight attitude).........	= 7.5	feet

(The C. G. was assumed to be under the cockpit and at a level slightly lower than the wing.)

<u>Take-Off Point</u>

The take-off point used in Part I of this report is that determined from the "flag" position since the film analysis indicated that, because of ground mirage and the nature of the flight path of the airplane during the period of breaking ground, the actual take-off point could not be definitely ascertained by photographic means.

It should be noted, however, that the "flag take-off" point is also not exact. Some idea of the probable magnitude of the difference between observed take-off points and the actual take-off point may be indicated by the following information obtained on Run No. 34. On this test the film indicated a take-off point somewhat closer (125 feet) to the starting point than the "flag take-off" point. The film records for Run No. 34 were examined with particular care and it is considered that the "film take-off" point so obtained is probably more nearly the correct location for the actual take-off. This instance is cited as an example of possible error by ground crew spotters and in order to furnish some indication of the probable accuracy of ground run distances shown in the summary table of Part I.

The above mentioned difficulties encountered in determining the exact take-off point are here recorded to provide information in order that the proper significance may be attached to ground run distances and it is suggested that the differences noted above in observed take-off distances are significant only in indicating that the reported take-off distance is not an infallible criterion for comparing ground run accelerations and that a more satisfactory comparison may be made by determining speeds attained at given distances along the flight path when the height of the airplane remains essentially unchanged.

Elevations

In the summarized data it has been assumed that the airplane has its landing gear retracted when clearing a 50-foot obstacle. For vertical elevations it was found that with the airplane in climbing attitude the film analysis reference point was 12 feet above the lowest point on the airplane. Therefore, on the work sheets, a reference-point elevation of 62 feet corresponds to clearing a 50-foot obstacle with wheels retracted.

The worksheet notes recording elevation of the airplane reference point include the 1/2-foot correction for apparent elevation of marker edge above ground level.

Calculations

Velocity calculations were based on intervals of five successive film readings. For the films having four exposures per second (all runs except 17, and 30 to 34) this corresponded to one second intervals.

PREPARED BY: Mr. Elisha N. Fales and
Mr. Norman N. Rubin

APPROVED BY Charles F. Dyer
Chief, Flight Engineering and
Factory Inspection Division

FILM ANALYSIS

AIRPLANE A-20-A
LOCATION Muroc Dry Lake
TIME OF DAY OR TEST NO. 6:45 P.M.

Sheet No. 22.
AIRPLANE IDENT. Run 10
DATE OF TEST 4-15-42
ANALYZED BY

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks.
0	3865	39.38		
	5224			
	3830	38.59		Start.
	3869	39.90	9.7	Take-off read from flag.
	75	40.41	16.1	Jets on.
	85	.92	21.6	
	98	41.43	27.6	
	3913	.94	33.3	
	31	42.44	38.7	
	52	.93	44.7	
	75	43.42	50.5	
	4001	.91	57.1	
	30	44.40	63.5	
	64	.89	68.9	
	4100	45.39	75.0	
	36	.87	80.9	
	77	46.36	86.5	
	4221	.85	92.2	
	66	47.31	97.4	
	4314	.80	101.5	
	63	48.27	107.8	
	4418	.77	114.1	
	74	49.24	119.3	
	4533	.72	125.3	
	92	50.19	128.8	
	4656	.67	133.5	
	4720	51.15	139.3	
	88	.63	144.7	
	4858	52.10	152.1	
17	94	.33	153.2	
17	4931	.57	155.3	
17	4967	52.81	156.4	
16	5004	53.04	157.4	
16	41	.27	160.6	
16	79	.51	163.8	
16	5118	.75	164.2	
16.5	56	.98	166.3	
16.5	97	54.22	171.0	
17	5237	.46	170.2	Take-off read from film.
17.5	77	.68	174.2	
17.5	5318	.92	179.3	
18	59	55.15	177.7	
18	5402	.38	179.8	
18	44	.62	183.0	

Sheet No. 22.

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks.
18.5	5487	55.86	183.0	
18.5	5531	56.09	187.1	
19	74	.32	188.2	
19	5616	.55	189.2	
19.5	62	.79	190.3	
20	5707	57.02	190.3	
20	51	.25	193.5	
20.5	95	.48	197.3	
21	5842	.72	197.8	
21	87	.95	202.2	
21	5933	58.17	204.4	
22	81	.40	202.2	
23	6023	.63	206.5	
24	75	.86	205.4	
25.5	6123	59.09	207.6	
27.5	70	.32	208.6	
29	6219	.55	208.6	
32	69	.79	212.0	
34.5	6317	60.02	210.8	
37.5	6365	60.24	213.0	
42	6415	.48	218.7	
46.5	65	.71	216.1	
49.5	6516	.93	223.1	
53.5	66	61.17	220.9	Left jet off.
58.5	6613	.39	220.4	
63.5	66	.62	223.9	
67.5	6721	.86	218.1	
73	72	62.09	223.4	
78.5	6823	.33	222.5	
82.5	78	.56	222.3	Right jet off.
87.5	6930	.80	222.3	
92.5	81	63.03	217.0	
96	7032	.27		

FILM ANALYSIS

Sheet No. 23.

AIRPLANE A-20-A AIRPLANE IDENT. Run 11.

LOCATION Muroc Dry Lake DATE OF TEST 4-18-42.

TIME OF DAY OR TEST NO. 9:50 A.M. ANALYZED BY

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks.
0	3965	9.42		Start.
	5484			Take-off from flag.
	3965.5	9.90	1.1	
	66	10.37	5.8	
	69.5	.85	9.2	
	76	11.33	14.7	
	83	.80	18.8	
	94	12.27	21.8	
	4005	.74	26.3	
	17	13.21	29.6	
	33	.69	35.1	
	50	14.16	40.7	
	71	.62	45.5	
	94	15.10	50.3	
	4118	.56	54.3	
	44	16.03	59.4	
	73	.50	63.5	
	4205	.97	69.3	
	38	17.45	73.2	
	75	.92	78.8	
	4312	18.40	82.0	
	51	.87	86.3	
	93	19.34	91.1	
	4437	.82	95.3	
	86	20.30	101.1	
	4534	.79	103.1	
	83	21.26	107.3	
	4635	.74	112.1	
	90	22.21	116.1	
	4747	.69	120.3	
	4806	23.18	123.8	
	66	.66	127.8	
	4929	24.14	132.8	
	95	.63	137.0	
	5061	25.10	141.1	
	5129	.58	144.5	
17.5	5200	26.06	148.4	
17.5	36	.30	150.7	
17	71	.54	152.1	
16	5307	.77	152.6	
16	43	27.00	155.3	
15.5	80	.25	155.8	Take-off read from film.
15.5	5417	.48	156.3	
15.5	55	.72	158.9	
15.5	93	.96	161.1	

Sheet No. 23 (Supp.).

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks.
16	5621	28.20	161.1	
16.5	70	.43	163.8	
18	5606	.67	166.0	
18.5	47	.90	164.2	
19	87	29.14	167.4	
19	5726	.38	167.4	
20.5	67	.62	166.7	
20.5	5806	.85	168.8	
22	47	30.10	175.0	
24	86	.34	172.2	
26	5926	.58	171.9	
27.5	73	30.82	174.0	
29	6012	31.06	169.5	
31	56	.30	175.0	
33.5	98	.54	180.2	
35.5	6141	.78	179.2	
37.5	85	32.02	177.3	
39.5	6227	32.26	179.4	
43	6270	.51	179.2	
46	6315	.75	179.4	
49.5	57	.98	182.3	
53.5	6401	33.23	181.3	
57	45	.47	178.8	
61	89	.71	183.3	
66	6532	.96	182.5	
70.5	77	34.19	181.4	
75.5	6622	.44	185.4	
81.5	65	.68	182.5	
88	6710	.92	181.5	
95	54	35.16	179.2	
98.5	96	.40		

Sheet No. 24.

FILM ANALYSIS

AIRPLANE A-20-A AIRPLANE IDENT. Run 12.
LOCATION Muroc Dry Lake DATE OF TEST 4-18-42
TIME OF DAY OR TEST NO. 10,10 A.M. ANALYZED BY

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks.
0	3961.5	30.83		
	5200			Start.
	3961.5	30.36		Take-off read from flag.
	3962.5	31.30	2.1	Jets on.
	63.5	.78	3.4	
	55	32.26	6.5	
	68	.74	10.9	
	75	33.22	15.6	
	84.5	.70	22.9	
	95	34.18	25.6	
	4012	.66	34.6	
	30	35.14	40.1	
	51	.62	44.3	
	72	36.10	49.5	
	97	.58	55.7	
	4125	37.06	63.0	
	56	.54	68.9	
	93	38.02	74.7	
	4230	.51	80.2	
	70	38.90	85.6	
	4313.5	.48	92.2	
	60	.97	99.0	
	4408	40.44	104.4	
	60	.92	110.9	
	4516	41.42	116.9	
	74	.90	123.1	
	4636	42.39	130.1	
	4700	.87	136.1	
	67	43.35	142.0	
	4838	.84	146.9	
16.5	4910	44.32	151.3	
16	4947	44.56	152.4	
16	85	.81	155.1	
15.5	5023	45.06	158.8	
15.5	62	.30	162.9	
15.5	5101	.53	168.6	
15.5	43	.78	171.3	
15.5	85	46.02	172.4	Take-off read from film.
15.5	5227	.26	172.4	
17	70	.51	174.5	
18	5312	.76	174.0	
19	56	47.00	176.6	

Sheet No. 34 (supp.)

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks.
21	5401	47.26	180.6	
22.5	45	.50	181.6.	
23.5	89	.74	184.5	
25.5	5534	.98	183.6	
27.5	80	46.23	188.8	
29.5	5626	.47	189.6	
31	74	.72	192.8	
32.5	5720	.96	195.9	
33.5	67	49.20	196.9	
3[illegible].5	5816	.44	196.9	
37.5	65	.69	201.0	
38.5	5913	.94	20[illegible].0	
40	62	50.17	207.4	
41.5	6012	.42	206.2	
42.5	62	.66	205.1	
44	6113	.91	210.3	
45.5	65	51.16	212.4	
47	6216	.39	214.4	
4[illegible]	68	.63	217.7	
51	6321	.83	219.8	
53.5	74	52.12	219.6	
56.5	6427	52.36	222.9	
60	81	.60	226.0	
64.5	6535	.84	221.6	
69	90	53.08	222.9	
73	6642	.32	222.9	Right jet off.
80	95	.56	221.9	Right jet on again.
84.5	6749	.80	224.7	Right jet off.
91	6803	54.04	226.[illegible]	
96	60	.29		
20.5	7750	58.10		Left jet off.

FILM ANALYSIS

Sheet No. 25.

AIRPLANE A-20-A AIRPLANE IDENT. Run 13.

LOCATION Muroc Dry Lake DATE OF TEST 4-18-42

TIME OF DAY OR TEST NO. 10:35 AM ANALYZED BY

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks.
0	3968	24.80		
	5469			Start.
	3965.5	25.28	7.3	Take-off read from flag.
	70	.76	12.6	
	76	26.23	17.0	
	87	.71	22.1	
	98	27.19	27.5	
	4012	.66	31.9	
	28	28.12	37.4	
	47	.59	41.7	
	68	29.06	45.5	
	90	.53	49.7	
	4113	.99	53.2	
	40	30.46	58.4	
	67	.92	63.8	
	98	31.38	69.5	
	4231	.84	72.6	
	66	32.30	76.9	
	4302	.78	80.7	
	41	33.24	84.5	
	82	.71	89.7	
	4424	34.17	94.1	
	68	.63	98.9	
	4516	35.10	103.2	
	66	.58	106.9	
	4617	36.04	111.2	
	70	.52	115.3	
	4725	.98	119.0	
	83	37.45	125.9	
	4842	.93	128.0	
	4903	38.40	131.1	
	4967	38.87	135.3	
	5032	39.35	139.5	
	99	.83	143.2	
18	5168	40.30	148.1	
18	5204	.53	149.8	
19	39	.77	153.2	
17.5	76	41.01	151.6	
16.5	5312	.24	155.8	
16.5	48	.48	155.8	
15	87	.72	156.3	
15.5	5424	.96	158.8	
15.5	62	42.20	160.0	
16	5502	.45	161.5	Takeoff read from film.
17	39	.67	164.2	
16.5	79	.92	168.8	
17.5	5618	43.15	166.7	

Sheet No. 25. (Supp.).

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks.
17.5	5659	43.38	169.6	
17.5	99	.63	169.8	
17	5740	.87	168.4	
17.5	81	44.11	172.2	
18	5824	.36	173.2	
18.5	66	.60	175.3	
18.5	5908	.84	174.2	
20	51	45.08	175.3	
20.5	93	.33	177.3	
21	6036	.57	176.5	
22	80	.81	179.4	
23.5	6124	46.06	180.4	
25.5	67	.30	178.6	
26.5	6211	.54	178.8	
29	55	.79	179.6	
30.5	99	47.04	180.6	
33.5	6343	47.28	181.4	
37	88	.52	183.3	
39	6431	.76	182.5	
43.5	75	48.00	182.6	
47	6520	.25	185.6	
49.5	65	.49	187.6	
53.5	6611	.73	187.5	
58.5	57	.97	190.5	
62	6700	49.21	190.6	
65	46	.44	186.5	
70.5	94	.69	190.5	
73.5	6838	.93	188.7	
78.5	81	50.16	184.4	
81	6925	.41	187.5	
86	71	.65	189.7	
89	7016	.89	186.5	
93	65	51.13	191.7	
97.5	7108	.37		

FILM ANALYSIS

Sheet No. 1.

AIRPLANE A-20-A AIRPLANE IDENT. Run 17.

LOCATION Muroc Dry Lake DATE OF TEST 4-19-42

TIME OF DAY OR TEST NO. 3:05 PM ANALYZED BY

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks.
0	3940	42.40		Start.
	5198			Take-off read from flag.
	3941	42.95		
	3942	43.50		
	3943	44.05	2.7	
	3945	.60	4.5	
	3947	45.17	8.4	
	3952	.73	13.3	
	3962	46.30	20.4	
	3975	.86	27.1	
	3993	47.42	33.3	
	4013	.98	38.9	
	4037	48.55	45.3	
	4063	49.11	52.2	
	4095	.67	58.3	
	4130	50.22	64.3	
	4167	.78	69.8	
	4207	51.35	75.7	
	4252	.92	82.2	
	4301	52.48	88.9	
	4352	53.03	96.0	
	4407	.60	101.8	
	4467	54.16	108.0	
	4530	.73	115.1	
	4596	55.29	120.4	
	4666	.85	125.4	
	4702	56.14	130.6	
	4739	.42	130.7	
	4777	.70	133.3	
	4815	.99	136.4	
	4854	57.28	138.6	
	4894.5	.56	141.0	
	4935	.84	144.7	
17.5	4956	.99	144.3	
17.0	4977	58.13	149.1	
16.5	4997	.27	150.0	
16.5	5020	.41	147.4	
16.5	5040	.55	153.6	
16.0	5061	.70	151.6	
16.0	5083	.83	155.4	
16.0	5105	.97	161.8	
16.0	5127	59.11	157.9	
16.0	5150	.25	155.2	

Sheet No. 1 (Supp.)

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks
16.0	5173	.40	159.6	Take-off read from film.
16.5	5195	.55	156.9	
16.5	5218	.68	159.4	
17.0	5241	.83	164.6	
18.0	5334	60.41	163.5	
18.5	5358	.54	180.5	
19.0	5406	.83	172.4	
19.5	5454	61.11	169.3	
20.5	5503	.39	174.1	
21.5	5551	.68	173.5	
22.0	5601	.95	172.8	
23.0	5650	62.24	175.4	
25.0	5700	.53	173.9	
25.0	5751	62.82	178.9	
26.0	5801	63.10	180.7	Right hand rocket off.
26.5	5854	.38	184.1	
28.5	5906	.67	185.8	
32.0	5959	.95	185.8	
35.0	6011	64.23	186.7	
38.0	6064	.51	186.7	
41.5	6117	.80	188.5	
45.5	6170	65.08	188.5	Note: Throttle slipped
48.0	6224	.36	187.7	part way closed during
51.0	6277	.64	189.5	run.
53.5	6331	.94	188.7	
57.0	6386	66.22	190.5	
60.5	6441	.51	196.5	
62.5	6498	.80	198.2	
66.0	6555	67.08	200.9	
69.5	6612	.36	200.0	
75.0	6668	.64	201.8	
77.5	6726	.94	199.1	
82.5	6785	68.22	200.0	
86.0	6841	.51		
91.5	6900	.80		Left hand rocket off.

Jets on at time 41.98.

FILM ANALYSIS

Sheet No. 2.

AIRPLANE A-20-A AIRPLANE IDENT. Run 18.

LOCATION Muroc Dry Lake DATE OF TEST 4-21-42

TIME OF DAY OF TEST NO. 7:10 A.M. ANALYZED BY

Height Ft.*	Dist. Ft.	Time Sec.	Vel. Ft/Sec.		Remarks
0	6167	3.03	0	Start	*True Elev. above ground,-
	4904			Flag	1' apparent elev. base.
		3.35		Jets on	Line above ground has
18.0	6166	3.35			been added.
	6165.5	.67			
	6165	.98	1.6		Trailing edge and top of
	6165	4.30	3.6		tail used as reference
	6164	.61	6.3		points for distance and
	6161	.92			height. - 16' above ground
	6157	5.24	13.6		at take-off, 11' above
	6146	.87	21.7		lowest point at 50'
	6131	6.48	29.3		obstacle.
	6110	7.10	38.0		
	6085	.70	46.7		
	6053	8.32	53.9		
	6017	.92	61.5		
	5978	9.55	69.4		
	5935	10.14	76.3		
	5885	.74	85.1		
	5834	11.32	92.7		
	5778	.90	99.1		
	5718	12.48	107.2		
	5653	13.08	114.4		
	5582	.67	121.5		
	5508	14.26	128.7		
	5430	.85	134.6		
	5348	15.45	141.5		
17.5	5305	.75	144.6		
17.5	5263	16.04	148.7		
	5219	.32	154.4		
	5174	.62	156.0		
	5129	.89	156.4		
	5082	17.20	161.2		
16.5	5036	.49	161.9		
16.5	4987	.78	166.7		Take-off
15.5	4938	18.07	17[illegible].9		
16.6	4887	.37	172.6		
17.5	4836	.66	175.9		
19.5	4785	.95	178.3		
20.5	4734	19.23	179.8		
22.0	4682	.52	183.6		
24.0	4631	.80	185.8		
26.0	4577.5	20.08	1[illegible]8.5		
28.0	4524	20.36	189.5		
31.5	4469	.65	190.8		
35.0	4415	.94	192.2		
39.5	4360	21.22	192.2		

Sheet No. 2.

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks.
43.0	4303	21.51	199.1	
47.0	4248	.80	200.9	
52.5	4192	22.06	205.6	
58.0	4136	.34	206.2	
64.5	4077	.62	206.3	
70.5	4012	.90	206.3	
76.5	3963	23.17	206.3	
83.0	3906	.45	203.1	
90.5	3846	.74	203.1	
97.0	3788	24.01		
162.5	3177	26.74		Both jets off.

FILM ANALYSIS   Sheet No. 3.

AIRPLANE A-20-A   AIRPLANE IDENT. Run 19

LOCATION Muroc Dry Lake   DATE OF TEST 4-21-42

TIME OF DAY OR TEST NO. 9:00 A.M.   ANALYZED BY

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks
0	6078.5	35.36		Start.
	4898			Take-off read from flag.
		35.65		Jets on.
	6075	36.20		
	6070	.77	14.1	
	6059	37.33	19.8	
	6047	.88	26.7	
	6031	38.42	32.7	
	6011	.98	39.1	
	5987	39.53	46.3	
	5961	40.08	53.5	
	5930	.60	60.9	
	5895	41.15	69.3	
	5856	.68	76.4	
	5812	42.23	84.0	
	5765	.76	91.0	
	5716	43.28	97.6	
	5663	.80	103.3	
	5606	44.34	109.8	
	5545	.89	115.3	
	5481	45.42	122.7	
	5415	.95	128.7	
	5347	46.45	134.9	
17.5	5312	46.72	138.5	
	5276	.98	139.6	
	5239	47.25	143.4	
	5199	.51	146.2	
	5160	.78	150.5	
	5121	48.04	151.0	
	5081	.30	153.8	
	5042	.55	156.7	
15.5	5000	.82	158.1	Take-off read from film.
15.0	4958	49.08	162.9	
15.5	4915	.35	164.5	
16.0	4871	.60	168.2	
17.0	4824	.89	171.0	
18.5	4778	50.15	170.6	
19.5	4732	.42	173.6	
21.0	4685	.69	173.6	
22.5	4640	.95	174.5	
25.0	4594	51.21	177.9	
27.5	4547	.48	179.0	
30.5	4500	.73	183.7	
34.5	4452	52.00	187.4	
37.5	4403	.25	187.6	
41.0	4354	.51	193.1	
45.0	4303	.78	190.5	
49.0	4255	53.02	194.2	

Sheet No. 3 (Supp.)

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks
54.0	4203	.30	194.2	
59.0	4152	.55	193.5	
63.5	4101	.82	197.1	
68.5	4048	54.09	198.1	
73.0	3996	54.35	200.0	
77.5	3944	.60	204.9	
81.5	3891	.87	203.8	
86.5	3837	55.12	205.7	
90.5	3784	.39		
95.0	3728	.65	79.0	
160.0	2940	59.23		Right jet off.
168.0	2325	.74		Left jet off.

FILM ANALYSIS

Sheet No. 4.

AIRPLANE A-20-A AIRPLANE IDENT. Run 20.

LOCATION Muroc Dry Lake DATE OF TEST 4-21-42

TIME OF DAY OR TEST NO. 9:20 A.M. ANALYZED BY

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks
0	6040	8.05		Start. (See Note)
	4263			Take-off read from flag.
	6031	8.57	18.3	
	6021	9.09	23.2	
	6009	.60	27.5	
	5992	10.12	32.5	
	5974	.64	38.2	
	5954	11.15	41.8	
	5930	.67	46.6	
	5905	12.20	51.4	
	5877	.72	55.5	
	5846	13.25	61.1	
	5814	.76	65.7	
	5778	14.28	69.6	
	5741	.79	74.8	
	5702	15.32	79.0	
	5660	.82	83.3	
	5616	16.33	88.2	
	5571	.83	92.2	
	5523	17.35	96.6	
	5472	.86	100.5	
	5419	18.37	105.9	
	5365	.88	110.3	
	5308	19.38	114.8	
	5248	.89	119.8	
	5186	20.40	123.0	
	5123	.90	127.6	
	5057	21.42	131.2	
	4989	.92	135.0	
	4921	22.42	139.8	
	4849	.93	142.6	
	4776	23.43	145.8	
	4701	.94	149.7	
	4625	24.45	153.7	
17.5	4585	.70	155.9	
17.5	4545	.96	159.4	
17.5	4505	25.20	160.4	
17.0	4464	.46	164.6	
17.0	4423	.71	163.4	
17.0	4382	.95	165.0	
15.5	4340	26.21	164.4	
15.0	4299	.46	164.7	
15.0	4257	.72	164.3	
15.5	4214	.97	168.6	Take-off read from film.
16.0	4170	27.22	172.3	
16.5	4127	.48	172.8	
17.5	4083	.73	174.5	

Sheet No. 4 (Supp.)

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks
18.0	4036	28.00	178.2	
19.0	3992	.24	179.2	
20.5	3947	.49	183.7	
22.0	3902	.74	181.0	
23.0	3856	.98	182.0	
24.5	3811	29.24	184.0	
26.5	3765	.49	183.2	
29.0	3718	.74	186.1	
31.5	3671	.99	188.1	
33.5	3623	30.25	190.1	
35.5	3575	.50	190.1	
37.5	3526	.75	193.0	
39.5	3479	31.00	193.0	
42.0	3430	.25	192.0	
44.5	3382	.50	196.0	
47.5	3334	31.75	194.0	
49.5	3285	.99	196.0	
55.0	3236	32.25	198.0	
57.5	3186	.50	199.0	
61.0	3136	.75	201.0	
65.0	3084	33.00	201.0	
67.5	3033	.26	202.0	
72.5	2981	.52	200.0	
75.5	2930	.77	201.0	
80.5	2880	34.02	205.0	
82.5	2830	.27	206.0	
88.5	2776	.52		
91.0	2724	.77		Camera Started late, Start calculated as 6050 feet, 6.58 seconds.

FILM ANALYSIS

Sheet No. 5.

AIRPLANE A-20A AIRPLANE IDENT. Run 21.

LOCATION Muroc Dry Lake DATE OF TEST 4-21-42

TIME OF DAY OR TEST NO. 1:15 P.M. ANALYZED BY

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks
0	6047			
	4402	21.28		Start.
	6045			Take-off read from flag.
	6042	21.82		
	6036	22.37		
	6027	.90	13.9	
	6015	23.45	18.7	
	6002	.98	23.3	
	5985	24.51	28.3	
	5967	25.05	32.7	
	5946	.57	37.8	
	5923	26.09	41.8	
	5899	.60	46.4	
	5870	27.13	50.7	
	5840	.66	54.5	
	5809	28.18	59.8	
	5774	.69	63.5	
	5736	29.22	67.4	
	5695	.77	67.9	
	5651	30.33	76.7	
	5606	.87	81.2	
	5559	31.41	85.6	
	5510	.95	89.4	
	5458	32.49	93.5	
	5405	33.03	96.7	
	5351	.56	101.4	
	5293	34.10	105.2	
	5234	.63	108.8	
	5171	35.16	112.6	
	5109	.71	116.4	
	5045	36.25	120.3	
	4979	.76	124.4	
	4911	37.28	128.7	
17.0	4840	.80	131.4	
17.0	4769	38.34	134.8	
16.5	4732	.86	137.6	
16.5	4696	39.12	138.1	
16.5	4659	.38	141.3	
15.5	4622	.65	142.7	
15.5	4585	.90	146.1	
15.5	4547	40.15	148.0	
15.5	4508	.40	147.6	
15.0	4470	.67	149.5	
15.0	4431	.93	149.0	
		41.18	151.0	Take-off read from film.

Sheet No. 5 (Supp.)

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks
15.5	4392	.44	153.5	
16.0	4354	.69	152.9	
16.5	4315	.94	159.4	
18.0	4275	42.20	154.4	
18.5	4231	.45	155.3	
19.5	4195	.72	157.8	
21.0	4155	.97	154.4	
23.5	4114	43.22	162.4	
25.5	4072	.48	161.8	
27.0	4031	.73	160.2	
29.5	3990	.99	161.8	
31.5	3949	44.25	162.1	
34.5	3907	.50	163.1	
36.5	3864	.76	165.0	
38.5	3822	45.02	163.8	
41.0	3779	.28	166.3	
43.0	3735	.55	170.2	
44.5	3691	.80	172.8	
46.5	3645	46.06	174.8	
48.0	3601	.31	176.5	
50.5	3555	.57	175.5	
52.0	3511	.82	174.0	
53.5	3466	47.08	174.8	
56.5	3420	.35	175.7	
58.0	3375	.60	175.7	
62.0	3330	.85	177.2	
63.5	3285	48.11	177.5	
68.0	3241	.36	179.4	
70.5	3194	.62	183.2	
73.0	3147	.87	185.1	
76.0	3100	49.12	183.0	
77.0	3054	.37	187.0	
79.5	3006	.62	187.0	
81.0	2960	.87	188.0	
82.0	2913	50.12	188.0	
85.0	2866	.37	190.0	
87.5	2818	.62	188.1	
90.5	2770	.87		
91.0	2723	51.13		

Sheet No. 6.

FILM ANALYSIS

AIRPLANE A-20-A AIRPLANE IDENT. Run 22.

LOCATION Muroc Dry Lake DATE OF TEST 4-21-42

TIME OF DAY OR TEST NO. 1:55 p.m. ANALYZED BY

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks.
0	6080.5	41.65		Start.
	4905			Take-off read from flag.
		41.65		Jets on.
	6080	42.23		
	6077	42.81	9.3	
	71	43.38	17.1	
	59	.95	24.3	
	41	44.51	31.7	
	22	45.07	39.0	
	00	.62	45.2	
	5972	46.18	51.6	
	42	.72	59.3	
	06	47.28	67.0	
	5869	.83	71.0	
	24	48.39	77.4	
	5783	.96	83.1	
	37	49.49	88.0	
	5687	50.02	98.1	
	34	.55	101.4	
	5574	51.09	107.0	
	20	.63	112.7	
	5486	52.16	116.1	
	5394	.68	125.4	
	29	53.20	130.0	
	5258	53.72	135.9	
	5221	53.98	139.5	
	5185	54.25	141.9	
	5146	54.52	143.3	
16	5110	54.77	147.1	Take-off read from film.
15.5	5072	55.02	148.1	
15.5	5035	55.28	151.2	
15.5	4996	55.52	153.9	
15	4955	55.78	155.1	
15.5	4916	56.04	156.2	
16	4875	56.30	160.0	
17	4834	56.56	159.6	
18	4792	56.82	163.1	
19	4750	57.08	165.0	
21	4707	57.33	166.7	
23	4654	.58	168.6	
24.5	4622	.84	171.3	
25.5	4578	58.10	172.3	
27.5	4534	.34	174.3	

Sheet No. 6 (Supp.)

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft. Sec.	Remarks
[illegible].5	4489	58.80	175.6	
[illegible]0.5	45	.65	175.[illegible]	
[illegible].5	4509	59.10	179.4	
34	28	.36	182.4	
33.5	07	.63	179.6	
36.5	4560	.87	185.4	
41.[illegible]	14	60.12	18[illegible].5	
44	4167	.39	18[illegible].5	
46	20	.64	18[illegible].3	
49	4071	60.90	191.1	
53	[illegible]	61.15	19[illegible].1	
57	3974	.4[illegible]	198.0	
61.5	[illegible]	.65	190.0	
64.5	3872	.91	197.1	
69.5	24	62.16	197.1	
73.5	3773	.42	19[illegible].1	
77	22	.66	199.0	
81	3673	.88	200.0	
86	21	63.18	201.0	
85.[illegible]	3571	.43	20[illegible].9	
92	19	.69		
94.5	34[illegible]	.[illegible]		

FILM ANALYSIS

AIRPLANE A-20-A AIRPLANE IDENT. Run 23. Sheet No. 7.

LOCATION Muroc Dry Lake DATE OF TEST 4-21-42

TIME OF DAY OR TEST NO. 2:05 P.M. ANALYZED BY

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks.
0	6062	47.23		
	4482			Start.
	6058	47.78		Take-off read from flag.
	54	48.32	6.0	
	47	.86	14.4	
	39	49.41	19.5	
	27	.94	25.0	
	12	50.47	30.8	
	5993	51.02	36.0	
	73	.55	41.3	
	50	52.08	46.7	
	24	.60	51.9	
	5895	53.12	54.8	
	64	.65	58.8	
	35	54.18	62.1	
	00	.71	66.0	
	5764	55.23	72.0	
	26	.74	75.2	
	5686	56.25	78.7	
	45	.77	83.1	
	01	57.30	87.9	
	5554	.81	91.7	
	05	58.31	97.0	
	5457	58.82	100.5	
	04	59.33	103.4	
	5348	.86	109.2	
	5291	60.38	112.7	
	32	.38	116.8	
	5174	61.37	120.8	
	12	.88	123.0	
	5047	62.40	126.7	
	4931	.92	130.2	
	13	63.43	134.3	
	4345	.93	137.3	
17.5	4844	63.93	137.3	
16.5	09	64.18	138.6	
16.5	4773	.44	138.8	
15.5	37	.68	142.2	
16	01	.96	142.6	
16	4664	65.20	144.6	
15.5	26	.46	145.1	
15.5	4569	.71	146.6	
15.5	53	.97	148.8	
15.5	14	66.22	150.0	Take-off read from film.

Sheet No. 7 (Supp.)

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks.
15.6	4477	66.46	149.7	
16	37	.74	152.[illegible]	
16.[illegible]	4399	.90	1[illegible].4	
1[illegible].5	58	67.24	155.[illegible]	
16.5	19	.51	160.[illegible]	
17.5	4278	.76	155.3	
18	39	68.01	1[illegible].4	
19	4198	.27	158.4	
20.5	58	.52	158.3	
22	18	.77	151.4	
22.5	4076	69.04	160.2	
23.5	35	.28	162.1	
24	3993	.55	163.7	
25.6	51	.80	16[illegible].5	
26.5	09	70.06	168.6	
27.5	3865	.32	171.6	
27.5	21	.57	173.3	
28.5	3776	.82	173.3	
28.5	34	71.07	172.3	
2[illegible].5	38[illegible]	71.33	170.6	
30.[illegible]	3647	.58	173.8	
31	02	.84	173.6	
32	3555	72.10	177.7	
33	11	.36	178.6	
34	3464	.61	178.4	
34.5	18	.87	182.2	
36	3373	73.12	181.2	
35.5	27	.37	181.2	
37	3281	.62	184.0	
38.5	35	.88	183.[illegible]	
41	3189	74.12	181.6	
42	40	.39	182.5	
44	3094	.65	180.0	
45.5	47	.91	180.8	
48	00	75.17	184.5	
49	2952	.43	187.4	
51	04	.68	187.4	
53	2854	.94	1[illegible].4	
54.5	07	76.20	1[illegible].2	
58	2768	.45	188	
6[illegible].[illegible]	10	.70	192	
63.5	2662	.96	191	Ran beyond markers.
67.0	2613	77.22	165	
70.	256[illegible]	.46		
72.5	2516	.75		

Sheet No. 8.

FILM ANALYSIS

AIRPLANE A-20-A AIRPLANE IDENT. 24

LOCATION Muroc Dry Lake DATE OF TEST 4-21-42

TIME OF DAY OR TEST NO. 4:15 PM ANALYZED BY

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks.
18.5	6074	58.68		Start
	6074	58.10		Jets on.
	4671			Take-off read from flag.
	6070	59.26	8.8	
	64	.82	15.5	
	54	60.39	21.3	
	39	.94	24.6	
	22	61.51	30.1	
	09	62.06	35.7	
	5986	.65	42.0	
	57	63.24	50.4	
	25	.82	57.9	
	5892	64.38	63.6	
	54	.93	69.8	
	14	65.49	77.0	
	5770	66.04	83.0	
	21	.60	90.0	
	5669	67.16	96.4	
	15	.70	101.8	
	5558	68.24	108.8	
	5499	.78	114.4	
	36	69.30	120.6	
	5369	.85	127.4	
	5300	70.38	131.5	
	5229	.90	138.4	
	5156	71.43	142.9	
[illegible]	5077	71.97	[illegible]	
18	37	72.23	151.6	
17.5	4997	.50	154.3	
17.5	55	.76	156.2	
17.5	15	73.02	161.2	
17.5	4873	.28	161.5	
17.5	31	.53	166.0	
16.5	4787	.80	168.9	
16	[illegible]	74.05	170.2	Take-off read from film
16	4699	.31	173.1	
15.75	54	.57	175.2	
16.5	07	.84	174.5	
16.5	4560	75.10	177.4	

Sheet No. 8 (Supp.)

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks.
17.5	4514	75.37	184.8	
18	4466	.63	181.7	
20.5	13	.89	186.4	
22.5	4371	76.14	183.2	
25.5	22	.40	183.3	
27.5	4274	.65	188.5	
30	26	.91	189.3	
33.5	4175	77.18	190.4	
36.5	27	.42	194.2	
40.5	4076	.69	196.1	
44	26	.94	193.3	
48.5	3975	78.20	198.0	
53.5	26	.46	197.1	
58.5	3874	.71	200.0	
64.5	23	.97	202.0	
70.5	3773	79.21	202.0	
75.5	22	.47	201.0	
82	3670	.72	201.0	
87.5	20	.98	202.9	
94.5	3566	80.24		
100.5	15	.49		
122	3369	81.26		Right jet off.
131.5	3254	81.76		Left jet off.

Sheet No. 9.

FILM ANALYSIS

AIRPLANE A-20-A AIRPLANE IDENT. Run 25.

LOCATION Muroc Dry Lake DATE OF TEST 4-22-42

TIME OF DAY OR TEST NO. 8:55 A.M. ANALYZED BY

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks.
0	6070.5	56.15	18.5	Start.
	4087			Take-off read at flag.
	6070	46.70	3.2	
	67	47.25	9.9	
	50	.78	15.5	
	49	48.35	20.8	
	36	.90	25.2	
	20	49.51	30.0	
	00	50.12	35.4	
	5978	.70	40.6	
	51	51.30	46.9	
	23	.90	51.7	
	5888	52.51	57.0	
	55	53.12	62.1	
	13	.72	67.1	
	5774	54.30	75.7	
	29	.52	76.2	
	5675	55.47	81.3	
	34	56.07	85.5	
	5583	.65	87.1	
	26	57.25	95.3	
	5472	.80	100.4	
	13	58.35	104.3	
	5350	58.97	109.4	
	5285	59.56	113.9	
	17	60.13	118.8	
	5150	.70	123.6	
	5078	61.26	126.1	
	06	.32	130.8	
	4932	62.39	134.8	
	4857	.94	139.1	
	4780	63.47	14[illegible].4	
	00	34.02	149.5	
	4618	.58	149.1	
	4531	65.12	153.7	
	4452	.67	157.9	
16	4408	75.94	156.8	
16	4366	76.20	159.3	
15.5	4321	.47	165.1	
15.5	4277	.74	164.8	
15.5	4233	77.00	165.7	
15.5	4187	.28	162.7	
15.5	4142	.56	.67.0	

Sheet No. 9 (Supp.)

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks.
15.5	4097	77.82	168.5	
16.0	4051	78.09	169.4	
16.5	4005	.36	169.4	Take-off read at film.
17.5	3959	.63	172.9	
18.0	3914	.90	175.5	
19.0	3866	79.16	177.4	
20.5	3819	.42	182.1	
21.5	3771	.69	179.4	
22.5	3721	.96	181.5	
24.5	3674	80.23	183.2	
25.5	3626	.49	181.3	
27.0	3575	.76	183.2	
28.0	3527	81.03	184.1	
29.0	3478	.30	186.0	
30.5	3428	.56	189.6	
31.5	3378	.83	193.3	
33.5	3328	82.09	193.3	
35.5	3275	.35	193.3	
38.5	3225	.61	194.2	
40.0	3175	.87	193.3	
42.5	3124	83.13	195.2	
45.5	3072	.40	197.1	
48.0	3020	83.66	196.2	
51.0	2970	.91	195.2	Ran beyond markers.
53.0	2918	84.18	197.1	
57.0	2867	.45	198.1	
60.0	2813	.71	200.0	
63.5	2760	.97		
66.0	2708	85.23		

FILM ANALYSIS

Sheet No. 10.

AIRPLANE A-20-A AIRPLANE IDENT. Run 26.
LOCATION Muroc Dry Lake DATE OF TEST 4-22-42
TIME OF DAY OR TEST NO. 9:10 A.M. ANALYZED BY

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks.
0	6023	43.65		First frame - start not caught by camera.
	4260			Take-off read from flag.
	6005	44.12	33.0	
	5986	.67	38.2	
	63	45.22	44.7	
	30	.75	48.1	
	09	46.27	52.6	
	5882	.81	58.1	
	50	47.37	60.6	
	14	.90	67.0	
	5778	48.43	72.3	
	38	.96	76.4	
	5626	49.60	81.5	
	46	50.70	85.3	
	5593	.70	90.6	
	40	51.28	95.7	
	5483	.85	100.4	
	24	52.42	105.3	
	5362	53.00	109.2	
	00	.56	113.7	
	5234-	54.13	118.2	
	5166	.69	123.0	
	5096	55.25	127.1	
	5022	55.82	130.9	
	4948	56.38	134.1	
	4874	.92	138.6	
	4797	57.48	142.7	
17.5	4756	.76	144.6	
17.6	4717	58.03	146.2	
17.0	4675	.31	149.1	
16.5	4634	.58	151.8	
16.5	4592	.86	151.6	
16.0	4550	59.13	152.7	
16.0	4508	.41	154.1	
15.5	4466	.68	155.0	
15.5	4424	.95	157.4	
15.5	4381	60.22	157.8	
15.6	4338	.49	159.1	
15.5	4294	.77	160.9	
15.5	4249	61.05	163.3	Take-off read from film.
16.0	4204	.32	165.7	
17.0	4160	.58	167.0	
18.5	4115	.85	167.0	

Sheet No. 10 (Supp.)

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks.
20.0	4072	62.11	165.4	
21.0	4027	.36	167.0	
22.0	3983	.65	168.2	
23.5	3938	.91	169.2	
25.0	3892	63.18	170.6	
26.5	3846	.45	172.5	
27.5	3791	.74	173.4	
30.0	3750	64.00	175.9	
31.5	3703	.27	178.1	
33.5	3650	.53	180.0	
35.5	3610	.79	180.8	
37.5	3561	65.05	180.0	
40.0	3516	.31	182.9	
42.0	3467	65.58	178.5	
45.0	3418	.84	180.7	
47.5	3370	66.12	185.2	
51.0	3318	.40	183.5	
53.0	3267	.66	186.9	
57.5	3218	.93	186.6	
60.0	3170	67.19	187.6	
63.0	3120	.45	190.4	
66.0	3070	.71	192.3	
69.5	3020	.97	190.4	
70.5	2970	68.23	189.5	
73.0	2922	.49	192.4	
75.5	2871	.76	191.5	
77.0	2818	69.02	194.3	
79.5	2767	.29	195.2	
81.5	2716	.55	195.2	
84.5	2666	.81		
88.0	2615	70.08		Start calculated as distance 6066, time 40.47.

FILM ANALYSIS Sheet No. 11.

AIRPLANE A-20-A AIRPLANE IDENT.& Run 27.

LOCATION Muroc Dry Lake DATE OF TEST 4-22-42

TIME OF DAY OR TEST NO. 9:45 A.M. ANALYZED BY

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks.
0	6083	17.71		Start.
	4838			Take-off read from flag.
	6083	17.71		Jets on.
	6082	18.22	4.2	
	78	.91	10.5	
	69	19.50	16.0	
	53	20.08	23.2	
	47	.66	28.7	
	24	21.24	36.1	
	03	.80	46.0	
	5976	22.35	51.8	
	44	.90	60.1	
	08	23.48	66.8	
	5869	24.03	72.5	
	27	.58	80.5	
	5782	25.13	86.8	
	31	.58	93.2	
	5678	26.23	99.5	
	22	.78	105.0	
	5564	27.32	111.5	
	02	.86	116.5	
	5436	28.40	122.5	
	5368	.96	129.0	
	5297	29.50	133.8	
17.5	5222	30.03	140.8	
17.5	5185	.30	144.0	
17.5	5147	.58	146.3	
17.5	5107	.83	149.1	
17.5	5068	31.09	151.4	
17.0	5027	.36	154.2	
16.5	4985	.63	158.5	
16.5	4942	.90	160.4	
15.6	4900	32.15	161.3	Take-off read from film.
15.5	4857	.42	162.9	
16.0	4814	.69	162.6	
16.5	4771	.95	164.2	
18.0	4726	33.22	169.2	
19.0	4683	.48	172.1	
20.5	4638	.73	174.5	
22.0	4592	.99	176.6	
23.5	4546	34.26	177.9	
25.5	4499	.51	180.6	
28.0	4453	.77	181.7	

Sheet No. 11 (Supp.).

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks.
30.5	4406	35.02	180.0	
33.0	4357	.29	187.4	
35.5	4310	.56	184.8	
38.5	4260	.80	188.5	
42.5	4212	36.07	191.3	
46.5	4161	.33	189.8	
49.5	4111	.60	194.3	
53.0	4059	.85	197.1	
57.5	4008	37.12	200.0	
60.5	3958	37.37	201.0	
63.5	3905	.63	202.9	
67.5	3854	.88	201.0	
71.5	3801	38.14	204.9	
76.5	3749	.40	202.9	
81.0	3696	.65	203.9	
86.5	3645	.91	205.5	
92.0	3591	39.17		
95.5	3557	.43		
115.5	3374	40.20		Right jet off.
139.5	3155	41.20		Left jet off.

Sheet No. 12.

FILM ANALYSIS

AIRPLANE A-20-A AIRPLANE IDENT. Run 28.

LOCATION Muroc Dry Lake DATE OF TEST 4/22/42

TIME OF DAY OR TEST NO. 9:40 a.m. ANALYZED BY

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks.
0	6071	31.98		Start. (See Note)
	4135			Take-off read from flag.
	6063	32.53	17.6	
	52	33.06	22.4	
	39	.60	27.4	
	23	34.12	32.9	
	05	.65	37.3	
	5983	35.16	41.4	
	61	.69	46.0	
	36	36.22	49.5	
	08	.76	55.5	
	5876	37.32	60.8	
	40	.87	66.9	
	01	38.44	71.6	
	5758	39.00	76.9	
	15	.57	81.2	Camera started late.
	5667	40.12	86.2	Start calculated as 6060
	20	.67	90.5	distance - 30.57 time.
	5566	41.23	94.1	
	15	.78	99.1	
	5460	42.32	104.6	
	02	.87	108.8	
	5341	43.40	113.1	
	5280	.94	117.4	
	16	44.46	120.5	
	5152	45.00	125.2	
	5082	.55	129.4	
	12	46.08	134.0	
	4941	.60	137.6	
	4868	47.12	140.6	
	4793	.65	144.3	
	4714	48.20	144.6	
	4635	.72	151.2	
	4560	49.25	155.3	
17	14	.51	158.4	
17	4474	.76	164.1	
17	33	50.02	157.7	
16.5	4391	.28	161.6	
16.5	50	.55	161.0	
16	06	.80	161.0	
16	4264	51.07	168.0	
16	22	.33	165.4	Take-off read from film.
16.5	4177	.58	168.9	
16.5	34	.84	172.5	
17	4090	52.10	171.6	

Sheet No. 12 (Supp.).

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks.
18	46	.35	173.6	
18.5	02	.60	174.5	
18	3957	.86	172.4	
18	12	53.12	174.3	
18.5	3865	.40	176.2	
18.5	19	.65	178.1	
19.5	3772	.91	181.6	
19.5	25	54.17	180.0	
21	3678	.43	183.5	
21.5	30	.70	184.5	
22	3583	.94	189.1	
23	35	55.20	192.0	
24	3487	.44	191.2	
25.5	38	.70	194.1	
27.5	3388	.96	189.4	
29	39	56.21	190.4	
30.5	3290	.46	193.1	
32	40	.74	191.3	
34	3191	56.98	195.1	
36	40	57.25	196.1	
38.5	3091	.50	196.1	
41	40	.76	198.0	
44	2989	58.01	198.0	
46.5	40	.[illegible]6	200.0	
49	2889	.52	200.0	
51	38	.77	199.0	
55.5	2787	59.02	200.0	
59.5	37	.28	198.1	
63	2687	.53		
66.5	34	.80		

FILM ANALYSIS

AIRPLANE A-20-A
LOCATION Muroc Dry Lake
TIME OF DAY OR TEST NO. 12:00 A.M.

AIRPLANE IDENT. Run 29.
DATE OF TEST 4-22-42
ANALYZED BY

Sheet No. 18.

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks.
0	6082	4.40		
	4295			
	6080			Start.
	6078	4.95	3.6	Take-off read from flag.
	6075	5.50	6.4	
	6068	6.04	9.2	
	6060	.58	14.0	
	6048	7.12	17.8	
	6037	.65	20.6	
	6024	8.18	24.3	
	6009	.70	27.1	
	5991	9.22	32.2	
	5970	.75	37.7	
	5946	10.26	42.5	
	5921	.77	47.8	
	5892	11.29	51.9	
	5862	.82	56.3	
	5829	12.34	60.[illegible]	
	5795	.85	65.4	
	5758	13.36	70.0	
	5720	.87	73.2	
	5679	14.37	77.6	
	5636	.90	81.4	
	5592	15.41	85.2	
	5542	.91	90.7	
	5484	16.46	94.6	
	5425	17.05	98.7	
	5366	.64	102.5	
	5305	18.20	107.0	
	5241	.77	111.7	
	5176	19.32	115.7	
	5108	.87	120.4	
	5039	20.43	124.1	
	4968	20.98	128.0	
	4897	21.52	131.3	
	4823	22.05	136.3	
	4746	.60	138.4	
	4669	23.13	141.9	
16.0	4629	.68	146.0	
16.0	4589	.[illegible]5	147.2	
15.5	4550	24.22	149.5	
15.5	4509	.49	14[illegible].6	
15.5	4469	.75	151.4	
		25.02	154.2	

Sheet No. 18.

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks
15.5	4427	25.29	153.7	Take-off read from film.
15.5	4385	.56	156.5	
15.5	4343	.83	157.5	
15.5	4301	26.08	160.0	
16.0	4260	.35	161.0	
16.0	4217	.31	159.3	
17.0	4174	.88	164.5	
17.0	4129	27.16	162.4	
18.0	4084	.42	165.7	
19.0	4040	.70	168.2	
19.5	3995	.96	168.2	
20.0	3949	28.23	170.8	
20.5	3904	.49	172.4	
21.0	3859	.76	173.1	
21.5	3814	29.01	173.1	
22.5	3769	.27	175.0	
23.0	3724	.53	174.3	
23.5	3677	.80	177.1	
24.5	3631	30.06	180.0	
25.5	3583	.32	182.9	
27.0	3536	.58	185.6	
28.5	3486	30.85	185.6	
30.5	3438	31.10	183.8	
32.0	3390	.36	184.6	
34.0	3342	.63	185.6	
36.0	3293	.89	183.0	
39.5	3245	32.14	164.6	
43.0	3196	.42	185.6	
45.5	3150	.67	182.1	
49.5	3100	.93	186.7	
52.0	3052	33.20	185.8	
54.5	3000	.47	186.8	
56.5	2953	.73	186.7	
59.5	2902	.99	187.4	
62.0	2856	34.25	187.4	
64.0	2807	.50	188.2	
67.5	2760	.76	192.2	
71.5	2710	35.01	196.1	
74.5	2660	.27		

Sheet No. 13.

FILM ANALYSIS

AIRPLANE A-20-A AIRPLANE IDENT. Run 30.

LOCATION Muroc Dry Lake DATE OF TEST 4-23-42

TIME OF DAY OR TEST NO. 1:20 P.M. ANALYZED BY

Height Ft.	Dist., Ft.	Time Sec.	Vel. Ft/Sec.	Remarks.
0	6170.5	9.35		Start.
	3846			Take-off read from flag.
	6168	9.91	6.8	
	6164	10.48	10.2	
	6157	11.05	14.1	
	6142	.61	18.9	
	6136	12.18	24.3	
	6121	.75	29.3	
	6102	13.31	33.9	
	6082	.86	39.2	
	6060	14.42	42.8	
	6034	.97	47.7	
	6007	15.53	53.4	
	5976	16.08	57.9	
	5942	.63	63.2	
	5906	17.18	67.4	
	5868	.73	71.9	
	5827	18.29	76.9	
	5783	.84	81.8	
	5736	19.39	86.8	
	5688	.93	91.3	
	5637	20.48	95.0	
	5584	21.02	98.6	
	5523	.58	103.2	
	5471	22.13	106.8	
	5411	.67	111.0	
	5350	23.21	115.2	
	5286	.76	117.9	
	5221	24.30	122.6	
	5154	.85	126.3	
	5084	25.38	130.0	
	5012	.93	134.7	
	4939	26.47	137.2	
	4863	27.01	140.8	
	4785	.56	145.2	
	4705	28.11	147.7	
	4624	.64	151.1	
	4541	29.19	154.3	
	4454	.75	157.0	
	4367	30.30	161.8	
	4277	.85	165.3	
	4185	31.39	168.8	
	4140	.67	170.3	
	4052	.94	170.3	

Sheet No. 13 (Supp.).

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks.
16.0	4045	32.22	174.5	
16.0	3996	.50	173.9	
16.0	3948	.77	176.6	
16.0	3899	33.05	180.0	
16.0	3849	.33	180.2	Take-off read from film.
16.5	3825	.47	181.9	
16.5	3798	.60	182.0	
17.0	3748	.88	185.5	
18.0	3697	34.16	185.5	
17.5	3645	.43	186.5	
18.0	3594	.70	189.1	
18.0	3541	.99	190.9	
18.5	3489	35.26	191.9	
18.5	3435	.53	192.8	
19.0	3381	.81	196.4	
20.0	3327	36.10	193.8	
20.0	3271	.37	196.4	
21.5	3218	.65	199.1	
23.0	3163	.92	200.0	
24.0	3108	37.20	201.8	
24.5	3051	.47	203.6	
25.5	2996	.75	204.5	
27.0	2939	38.02	206.4	
29.0	2883	.30	211.0	
31.0	2824	.57	209.1	
32.5	2766	.84	211.8	
34.5	2709	39.12	209.0	
36.0	2650	.40		Ran beyond markers.
38.5	2592	.68		
41.0	2553	.84	214	
45.5	01	40.10	211	
47.0	2446	.35	207	
49.5	2395	.61	214	
53.5	42	.86	217	
57.0	2285	41.11	217	
59.5	29	.35	220	
63.5	2180	.60	217	
67.5	24	.85		

FILM ANALYSIS   Sheet No. 14.

AIRPLANE A-20-A   AIRPLANE IDENT. Run 31.
LOCATION Muroc Dry Lake   DATE OF TEST 4-23-42
TIME OF DAY OR TEST NO. 1:55 P.M.   ANALYZED BY

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks.
0	6185	24.93		Start.
	4621			Take-off read from flag.
	6185	24.93		Jets on.
	6178	26.18	8.3	
	6170	.74	15.0	
	6156	27.31	25.0	
	6141	.87	31.3	
	6122	28.42	36.5	
	6100	.98	43.0	
	6075	29.53	50.0	
	6046	30.08	57.0	
	6011	.64	64.5	
	5974	31.19	70.9	
	5933	.73	77.2	
	5890	32.28	83.6	
	5842	.83	89.5	
	5790	33.39	96.4	
	5736	.93	102.3	
	5673	34.48	108.2	
	5617	35.03	113.6	
	5553	.58	119.0	
	5486	36.13	124.4	
	5415	.69	130.3	
	5342	37.24	136.4	
	5266	.79	141.8	
	5186	38.33	146.8	
	5103	.89	151.6	
	5018	39.45	156.8	
16.6	4930	40.00	162.7	
16.6	4885	.26	166.5	
16.5	4838	.56	169.7	
16.5	4792	.82	169.4	
16.0	4745	41.09	174.3	
16.5	4697	.37	175.5	
16.0	4672	.51	175.9	Take-off Read from film.
17.0	4648	.64	178.7	
17.5	4599	.92	179.1	
18.0	4550	42.20	180.2	
18.5	4500	.47	183.2	
20.0	4446	.75	186.4	
21.0	4392	43.02	191.7	
22.5	4346	.30	191.7	
24.0	4291	.56	189.9	

Sheet No. 14 (Supp.).

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks.
26.5	4239	43.84	199.1	
28.5	4185	44.11	195.6	
30.5	4130	.38	200.9	
32.5	4076	.66	201.8	
36.0	4020	.93	200.0	
39.5	3965	45.20	204.5	
43.5	3908	.49	204.5	
48.0	3851	.76	207.3	
52.5	3795	46.03	211.1	
56.5	3737	.30	213.0	
61.0	3680	.57	212.8	
65.5	3621	.84	212.8	
70.5	3563	47.12	215.6	
74.5	3505	.39	215.6	
78.5	3445	.66	216.5	
82.0	3386	.94	215.5	
87.5	3327	48.21	215.5	
91.5	3266	.49	219.3	
97.0	3208	.76	224.1	
100.0	3147	49.03		
76.5	3475			
		47.53		Both jets off.
		47.80		Left jet on again.
		48.21		Left jet off.

Sheet No. 15.

FILM ANALYSIS

AIRPLANE A-20-A AIRPLANE IDENT. Run 32.

LOCATION Muroc Dry Lake DATE OF TEST 4-23-42

TIME OF DAY OR TEST NO. 1:55 AM ANALYZED BY

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks.
0	6180	54.86		Start.
	3828			Take-off read from flag.
	6177	55.41	6.3	
	6173	.97	10.2	
	6166	56.54	14.2	
	6157	57.10	18.1	
	6145	.66	22.7	
	6132	58.23	27.9	
	6115	.79	33.1	
	6094	59.36	39.4	
	6070	.92	44.5	
	5943	60.49	49.6	
	6014	61.06	54.0	
	5982	.62	58.7	
	5948	62.18	63.3	
	5911	.74	67.7	
	5871	63.32	73.0	
	5829	.88	77.9	
	5783	64.44	83.1	
	5735	6500	88.1	
	5684	.57	91.6	
	5630	66.14	96.5	
	5575	.71	100.9	
	5516	67.27	105.3	
	5455	.84	110.2	
	5392	68.40	113.3	
	5327	.96	117.8	
	5260	69.53	121.4	
	5190	70.09	125.9	
	5120	.64	129.9	
	4891	72.33	140.9	
	4811	.89	145.1	
	4728	73.45	149.3	
	4644	74.01	152.9	
	4553	.56	155.8	
	4470	75.12	159.8	
	4379	.69	163.1	
	4236	76.25	166.7	
	4191	76.81	170.2	
17.0	4143	77.09	171.8	
17.0	4095	71.37	172.6	
17.0	4045	.65	174.3	
16.5	3996	.94	175.4	

Sheet No. 18 (Supp.).

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks.
16.5	3946	78.22	175.0	
16.5	3895	.51	179.5	
16.0	3870	.65	179.5	
16.5	3818	.93	183.7	Take-off read from film.
16.0	3768	79.21	182.3	
16.0	3715	.49	182.3	
16.5	3664	.78	186.6	
17.0	3612	80.06	155.5	
17.5	3559	.33	190.2	
17.5	3505	.62	191.2	
17.5	3451	.90	191.2	
17.5	3396	81.19	193.0	
17.5	3341	.47	193.9	
17.5	3285	.76	196.6	
18.5	3230	82.04	197.3	
19.0	3175	82.32	199.1	
20.0	3118	.60	201.8	
22.0	3060	.89	200.9	
23.0	3004	83.18	204.5	
25.0	2948	.45	207.1	
28.5	2889	.72	207.9	
31.5	2829	84.01	212.4	
35.0	2767	.30	210.5	
37.0	2708	.58	222	Ran beyond markers.
42.5	2640	.89	224	
44	2580	85.16	221	
47.5	2520	.43	217	
49	2463	.68	217	
52	2408	.94	213	
56	2352	86.21	215	
59.5	2296	.46	218	
64	2239	.73	215	
66.5	2184	.98		
74	2130	87.23		

Sheet No. 16.

FLIGHT ANALYSIS

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft./Sec.	Remarks.
	[illegible]	[illegible]		Start.
	[illegible]			[illegible] from Flag.
	[illegible]	[illegible]		[illegible]
	[illegible]	[illegible]	[illegible]	
	[illegible]	[illegible]	[illegible]	
	[illegible]	[illegible]	[illegible]	
	[illegible]	[illegible]	37.[illegible]	
	34	38.28	41.[illegible]	
	11	[illegible]	48.[illegible]	
	[illegible]07	54.[illegible]	[illegible]	
	[illegible]	[illegible]	61.[illegible]	
	[illegible]	[illegible].61	67.5	
	[illegible]	[illegible].07	7[illegible].2	
	[illegible]	.65	[illegible]	
	[illegible]07	[illegible].25	[illegible].3	
	07	[illegible]	[illegible]	
	[illegible]3	[illegible].34	[illegible]	
	[illegible]	[illegible]	104.4	
	[illegible]	[illegible]	[illegible]	
	[illegible]	[illegible]	117.8	
	[illegible]	[illegible]	[illegible]	
	[illegible]	[illegible]	123.2	
	[illegible]	[illegible]	[illegible]	
	[illegible]	[illegible].28	[illegible]	
	[illegible]	[illegible]	[illegible]	
	[illegible]	[illegible].42	[illegible]	
	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]		[illegible]	[illegible]	
[illegible]		[illegible]	[illegible]	
[illegible]		[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	Takeoff read from film.
[illegible]	[illegible]	[illegible]	172.[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible].72	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible].88	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]3	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	

Sheet No. 16. (Supp.).

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks.
29	4187	.73	195.8	
31.5	32	69.00	193.8	
35	4077	.29	195.6	
38	22	.58	197.3	
40.5	3966	.86	200.0	
44.5	09	70.13	204.5	
46	3853	.41	205.4	
52	3795	.69	205.4	
57.5	38	.97	206.3	
62.5	3681	71.24	206.4	
67	22	.53	205.9	
71.5	3565	.81	207.1	
78.5	3505	72.08	206.2	
85.5	3447	.37	207.1	Right jet off.
92.5	3389	.64		Left jet off.
96	3329	72.92		

FILM ANALYSIS   Sheet 17

AIRPLANE A-20-A   AIRPLANE IDENT. Run 34

LOCATION Muroc Dry Lake   DATE OF TEST 4-23-42

TIME OF DAY OR TEST NO. 4105 PM   ANALYZED BY

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks
	6154.5	17.74		Start
	4036			Take-off read from flag.
	6152	18.32	4.8	
	49	.8[illegible]	8.6	
	42	19.46	12.7	
	35	20.02	14.0	
	23	.60	22.0	
	10	21.16	28.1	
	6092	.73	32.7	
	71	22.30	38.5	
	49	.86	43.4	
	23	23.42	47.6	
	5994	.99	52.4	
	[illegible]	24.55	56.6	
	31	25.11	61.2	
	5905	.68	66.2	
	52	26.23	70.2	
	15	.80	75.0	
	5773	27.36	79.6	
	27	.92	83.6	
	5678	28.48	88.4	
	27	29.05	92.9	
	5574	.61	96.9	
	17	30.18	101.3	
	5460	.73	105.8	
	5399	31.30	109.8	
	35	.87	114.2	
	5271	32.42	118.3	
	[illegible]3	.98	122.4	
	5134	33.54	126.3	
	5062	34.10	129.3	
	4988	34.66	133.6	
	12	35.23	137.2	
	[illegible]	.80	141.2	
	4752	36.36	146.0	
	4669	.92	148.0	
	4585	37.47	152.2	
	[illegible]	38.03	155.1	
	4411	.60	159.1	
15.5	[illegible]	39.17	162.2	
15.5	4275	.44	166.6	
[illegible]	27	.72	16[illegible].7	

Sheet 17 (Supp.)

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks
15.5	4182	40.01	167.0	Take-off read from film.
15.5	58	.15	165.5	
15.5	35	.28	167.0	
16	4088	.56	171.8	
16	40	.84	171.2	
17	3993	41.11	172.1	
18.5	45	.39	173.9	
19	3897	.67	175.0	
20	47	.95	175.2	
20.5	3797	42.23	177.9	
22	47	.52	177.0	
23.5	3696	.80	177.9	
24.5	47	43.08	185.3	
25.5	3596	.36	179.5	
26.5	45	.63	183.8	
27.5	3495	.92	183.9	
29	43	44.19	184.8	
30.5	339[illegible]	.48	189.2	
33	38	.75	190.1	
34.5	3285	45.03	191.8	
37	32	.30	188.4	
38.5	3179	45.58	192.7	
40	3127	.87	190.2	
43.5	3073	46.13	192.9	
46.5	19	.42	198.2	
49.5	2963	.70	193.8	
[illegible].5	09	.97	199.1	
57.5	2856	47.25	196.4	
62	00	.52	198.2	
66	2747	.80		

FILM ANALYSIS

AIRPLANE A-20-A AIRPLANE IDENT. Run 35 Sheet No. 19.

LOCATION Muroc Dry Lake DATE OF TEST 4-23-42

TIME OF DAY OR TEST NO. 5:50 PM ANALYZED BY

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks
	6075	18.47		Start.
	4561			Take-off read from flag.
	6075	18.47		Jets on.
	6074.5	19.05	1.7	
	6073	19.63	6.1	
	6068	20.20	10.8	
	6061	.75	17.0	
	6050	21.31	23.2	
	6035	.86	29.7	
	6017	22.40	35.9	
	5996	.94	41.7	
	5972	23.48	47.7	
	5945	24.02	54.4	
	5914	.56	60.8	
	5878	25.11	67.1	
	5840	.65	74.3	
	5800	26.18	79.3	
	5755	.70	85.0	
	5709	27.24	91.5	
	5659	.78	95.8	
	5606	28.30	101.9	
	5551	.83	108.6	
	5494	29.35	112.8	
	5432	.87	119.1	
	5368	30.41	124.4	
	5302	.92	129.3	
	5234	31.44	135.9	
	5163	.95	140.4	
	5088	32.47	145.7	
	5010	33.00	150.7	
	4931	.52	155.3	
16.5	4848	34.04	161.1	
16.5	4807	34.30	163.5	
16.	4765	.55	166.3	
16	4720	.82	168.6	
15.5	4675	35.08	171.4	
15.5	4630	.35	172.4	
15.5	4585	.60	173.6	
15.5	4539	.87	176.2	
16	4491	36.14	177.4	Take-off read from film.
16.5	4445	.40	181.0	

Sheet 19 (Supp.)

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks
17	4397	36.66	183.7	
17.5	4349	.92	185.7	
18	4300	37.18	190.4	
19.5	4250	.45	190.6	
20.5	4199	.70	193.4	
20.5	4147	.98	198.1	
22.5	4095	38.24	195.3	
24	4042	.50	199.0	
[illegible]	[illegible]	.77	200.0	
[illegible]	[illegible]	39.03	201.9	
31	3885	.29	204.8	
33.5	3830	.55	206.7	
36	3777	.81	210.6	
39	3721	40.08	209.5	
42	3666	.33	213.3	
46.5	3610	.60	218.4	
50.5	3553	.86	217.1	
54.5	3496	41.11	219.0	
58.5	3438	.38	219.8	
62.5	3380	.65	218.7	Right jet off.
67	3320	.92	217.8	
70.5	3262	42.18	223.8	
74.5	3205	.45	226.0	
78	3145	42.70	227.9	
81.5	3085	.96	236.3	
85	3025	43.22	232.0	Left jet off.
89.5	2964	.47	233.3	
94	2906	.73		

FILM ANALYSIS | Sheet No. 20.

AIRPLANE A-20-A AIRPLANE IDENT. Run 36.

LOCATION Muroc Dry Lake DATE OF TEST 4-23-42

TIME OF DAY OR TEST NO. 4:05 P.M ANALYZED BY

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks.
0	6066.5	47.03		Start.
	3751			Take-off read from flag.
	6065.5	47.55	2.4	
	6064	48.08	6.2	
	6059	.60	10.7	
	6052	49.13	15.3	
	6043	.65	20.1	
	6031	50.17	25.0	
	6017	.69	29.5	
	6000	51.21	33.8	
	5981	.75	38.9	
	5960	52.27	42.9	
	5935	.80	47.1	
	5910	53.31	49.5	
	5882	.85	54.7	
	5855	54.39	59.3	
	5819	.92	64.6	
	5783	55.45	70.4	
	5745	.97	73.4	
	5705	56.52	76.3	
	5662	57.06	80.5	
	5619	.60	85.4	
	5572	58.12	89.6	
	5523	.65	94.8	
	5472	59.18	97.7	
	5418	.72	101.4	
	5364	60.25	105.2	
	5308	.77	109.5	
	5250	61.29	113.8	
	5188	.82	117.6	
	5125	62.35	120.9	
	5061	.87	124.9	
	4996	63.40	128.4	
	4927	.91	132.1	
	4858	64.43	136.5	
	4785	.96	138.6	
	4711	65.48	142.2	
	4636	66.01	146.6	
	4558	.54	150.7	
	4478	67.07	153.3	
	4393	.60	156.9	
	4308	68.15	159.8	
	4219	.70	162.3	
	4128	69.28	166.5	

Sheet No. 20.

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks
16.0	4082			
16.0	4036	.64	168.4	
15.5	3989	.80	170.9	
15.5	3940	70.09	173.4	
15.5	3893	.36	173.6	
15.5	3845	.63	177.1	
15.5	3796	.90	176.1	
16.5	3746	71.17	176.4	
16.5	3699	.45	178.9	Take-off read from film.
18.0	3650	.73	178.9	
18.5	3601	.99	184.1	
19.5	3551	72.26	185.0	
20.5	3501	.52	188.8	
21.5	3448	.80	190.7	
23.0	3395	73.06	192.7	
23.5	3341	.34	196.3	
25.0	3289	.61	196.3	
27.0	3236	.88	198.1	
29.5	3183	74.14	197.2	
31.0	3130	.41	199.1	
32.5	3076	.68	200.9	
34.5	3019	74.95	200.9	
36.0	2964	75.22	204.6	
38.0	2907	.50	209.3	
40.0	2850	.77	209.3	
42.5	2793	76.03	214.2	
45.0	2737	.30	215.1	
48.0	2679	.56	215.1	
50.5	2620	.83	216	
53.0	2562	77.09	217	Ran beyond markers.
55.5	2503	.37	221	
57.5	2442	.64	213	
61.0	2390	.90	216	
63.5	2329	78.17	220	
67.0	2270	.45	220	
70.0	2207	.70	226	
72.0	2150	.97	231	
76.5	2087	79.23	229	
		.50		

FILM ANALYSIS

Sheet No. 21

AIRPLANE A-20-A AIRPLANE IDENT. Run 37.

LOCATION Muroc Dry Lake DATE OF TEST 4-24-42

TIME OF DAY OR TEST NO. 9:15 AM. ANALYZED

Height Ft.	Dist. Ft.	Time Sec.	Vel. Ft/Sec.	Remarks
0	6064	33.36		
	4989			
	6064	33.36		Start.
	6062.5	34.08		Take-off read from flag.
	6055	.79	6.3	Jets on.
	6041	35.51	15.4	
	6020	36.22	24.9	
	5991	.95	34.6	
	5956	37.65	44.4	
	5914	38.37	53.7	
	5866	39.09	63.0	
	5812	.79	72.2	
	5751	40.49	80.9	
	5686	41.19	89.4	
	5613	.91	97.9	
	5536	42.61	106.0	
	5453	43.30	114.2	
	5365	44.00	122.9	
17.5	5313	.35	131.2	
17.0	5270	.70	134.7	
17.5	5221	45.05	139.3	
17.5	5170	.40	142.1	
17.0	5119	.75	145.7	
15.5	5066	46.10	149.6	
15.5	5013	.44	152.5	
16.0	4958	.79	156.4	
17.5	4902	47.12	159.4	Take-off read from film.
20.0	4846	.48	163.5	
22.5	4789	.81	164.4	
26.0	4730	48.16	166.7	
29.0	4672	.50	170.8	
33.5	4612	.85	172.3	
38.0	4553	49.18	175.6	
43.5	4493	.51	177.0	
49.5	4433	.85	181.2	
55.0	4371	50.18	182.1	
59.5	4309	.52	183.0	
66.0	4246	.86	184.4	
72.0	4184	51.20	187.3	
80.0	4120	.52	189.6	
86.5	4055	.86	190.4	
93.0	3989	52.21	197.0	
1[illegible]0.5	3924	.52	198.5	
222.0	3116	56.44		
227.5	3047	56.77		Right jet off.
				Last frame - Left jet still on.

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APPENDIX B

Breakdown of the Gross Weight of the Airplane For Each Flight

The gross weight of the A-20A airplane used in the flight tests was determined by weighing at Wright Field. At the time of weighing the airplane was fully fueled, had a crew of two on board, and carried the jet propulsion equipment installed by the Aircraft Laboratory (Cf. Part II of this report). The gross weight was found to be 18,304 lbs. Since weighing facilities were not available at Muroc, the weights of the airplane for each test had to be calculated. In the following weight breakdowns the weight of one gallon of gasoline will be taken to be 6 pounds.

The main gasoline tanks held 1518 lb. and the auxiliary tanks 648 lb. The jet equipment installed by the Project weighed approximately 912 lb. Thus, with the gasoline tanks empty and all jet equipment aboard the gross weight of the airplane was 18,304 - 1518 - 634 + 912 = 17,014 lbs.

To minimize time between flights the airplane gasoline tanks were not refilled after each flight. To determine the amount of gasoline used during one curcuit, including a take-off and return to the starting line, the circuit was repeated several times and the auxiliary tanks refilled. It was found that one curcuit required approximately 13 gallons or 78 lb. of gasoline.

The weight breakdown for each test is tabulated in Table 1-B.

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TABLE I-B (PART 1)

WEIGHT BREAKDOWN OF THE A-20A FOR EACH TEST

TEST NO.	10	11	12	13	14	15	16	17	18	19
Airplane weight, fuel tanks empty, lb	17,014	17,014	17,014	17,014	17,014	17,014	17,014	17,014	17,014	17,014
Main gasoline tanks	1,518									
Auxiliary gasoline tanks, full	684									
Auxiliary gasoline tanks less 1 circuit		606				606	606	606	606	
Auxiliary gasoline tanks less 2 circuits			528							528
Auxiliary gasoline tanks less 3 circuits				450						
Auxiliary gasoline tanks less 4 circuits					372					
Auxiliary gasoline tanks less 5 circuits										
Jet Propellants	288	288	288		288	288	288	288	288	288
Overload in form of lead shot										
Passenger plus parachute										
TOTAL WEIGHT	19,504	17,908	17,860	17,464	17,674	17,908	17,908	17,908	17,908	17,830

TABLE I-B (PART 2)

WEIGHT BREAKDOWN OF THE A-20A FOR EACH TEST

TEST NO.	20	21	22	23	24	25	26	27	28	29
Airplane weight, fuel tanks empty, lb	17,014	17,014	17,014	17,014	17,014	17,014	17,014	17,014	17,014	17,014
Main gasoline tanks		1,008	1,008	1,008	1,008	1,008	1,008	1,008	1,008	1,008
Auxiliary gasoline tanks, full										
Auxiliary gasoline tanks less 1 circuit		606				606				
Auxiliary gasoline tanks less 2 circuits			528				528			
Auxiliary gasoline tanks less 3 circuits	450			450				450		
Auxiliary gasoline tanks less 4 circuits					372				372	
Auxiliary gasoline tanks less 5 circuits										294
Jet Propellants		288	288		288	288	288	288		288
Overload in form of lead shot										
Passenger plus parachute										
TOTAL WEIGHT	17,464	18,916	18,838	18,472	18,682	18,916	18,838	18,760	18,394	18,604

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TABLE I-B (PART 3)

WEIGHT BREAKDOWN OF THE A-20A FOR EACH TEST

TEST NO.	30	31	32	33	34	35	36	37	38
Airplane weight, fuel tanks empty, lb	17,014	17,014	17,014	17,014	17,014	17,014	17,014	17,014	17,014
Main gasoline tanks	1,518	1,518	1,518	1,518	1,518	1,518	1,518		
Auxiliary gasoline tanks, full						684			
Auxiliary gasoline tanks less 1 circu	606						606		
Auxiliary gasoline tanks less 2 circuits		528						528	
Auxiliary gasoline tanks less 3 circuits			450						450
Auxiliary gasoline tanks less 4 circuits				372					
Auxiliary gasoline tanks less 5 circuits					294				
Jet Propellants	288	288		288		288		288	288
Overload in form of lead shot	240	240	240	240	240	240	240		
Passenger plus parachute	225	225	225	225	225	225	225		165
TOTAL WEIGHT	19,891	19,813	19,447	19,657	19,291	19,969	19,603	17,830	17,917

REEL – C

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A.T.I.

6577

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~~Melin~~

ORIGINATING AGENCY:

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ABSTRACT:

Tests were conducted on jet units to determine the effect on reduction of take-off run, distance to clear 50-ft obstacle, high speed, on stability and control, of blast on parts of the plane, and reliability. The jet motors and four propellant tanks were mounted in the rear of the engine nacelle cone, controls were in rear gunner's cockpit. The two jet units each supplied 1000 lb of thrust for 24 sec. The test showed: theoretically predicted values agreed, large increase in maximum speed, no difficulty with stability and control, no effect on parts after treatment, and reliability. Test performance are given in charts and graphs.

1 Apr 92

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